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CRYSTAL STRUCTURE OF VERMICULITES AND MIXED VERMICULITE-CHLORITES

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In studying the structure of hydrates related to the clay minerals it was a matter of some importance to reexamine the vermiculites. Gruner[1] using *x*-ray powder diffraction data showed that these minerals are formed of silicate layers, similar to those of talc,[2] with water molecules introduced between the layers. Such a structure accounts for the behavior of the vermiculites upon heating, and while the following work introduces essential revision in detail, this feature remains unchanged.

EXPERIMENTAL PROCEDURE AND SOURCE OF MATERIALS

Dr. C. S. Ross of the U. S. Geological Survey kindly gave us several analyzed samples of vermiculite. The two used for the larger part of this work were Specimen #3 and #5 as described by C. S. Ross, E. V. Shannon, and F. A. Gonyer.[3] Both were clear yellowish green varieties free from apparent impurities between the cleavage planes.

Single crystals suitable for study by *x*-ray diffraction methods were cut from large plates. After cutting, the crystals were compressed with moderate force in order to align the plates which were very flexible and easily distorted. These were used to obtain Weissenberg goniometer and rotating crystal photographs about the *a* and *b* axes. Lattice dimensions obtained from these photographs and from measurements of *d* (001) against (00*l*) of β Al_2O_3 as reference are:

$$\begin{array}{ll} d(001)=28.80\pm.10\text{Å} & c=28.85\pm.10\text{Å} \\ d(100)=\ 5.32\pm.05\text{Å} & b=\ 9.18\pm.05\text{Å} \\ & a=\ 5.33\pm.05\text{Å} \\ & \beta=93°15'\pm15' \end{array}$$

The monoclinic angle β was estimated on equatorial zone Weissenberg photographs about the *b* axis. More accurate values were obtained from the measured spacings of (20 26) and (20 $\overline{26}$). Values of a, b, and c are essentially in agreement with those found by Gruner, while β is about 4° smaller. The two samples gave values that checked closely.

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[1] Gruner, J. W., *Am. Mineral.*, vol. **19**, pp. 557–575, 1934.

[2] Pauling, Linus, *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 123–129, 1930.

[3] *Econ. Geol.*, vol. **23**, p. 536, 1928.

Intensities of the 8th to 28th orders of reflections of (001) or photographs of sample #5 made with FeKα-radiation were accurately measured by means of an integrating microphotometer, similar to the one described by B. W. Robinson.[4] These were reduced to an absolute basis by comparison with the (004) reflection from a roughened face of NaCl on photographs taken with a reference x-ray goniometer, under conditions of reflection corresponding to a thick crystal completely covering the slit. Intensities of the 30th to 52nd orders of reflection from (001) were estimated by comparison with the 8th to 28th orders on photographs made with MoKα-radiation. Intensities of (00l) reflections for CuKα-radiation from sample #3 were estimated to have the same relative values as the corresponding reflections of sample #5.

No correction was made for possible extinction in vermiculite since, as it will appear later, there was no entirely trustworthy method of calculating F values. Secondary extinction might be expected to be small for such poorly formed crystals. The linear absorption coefficient of vermiculite was taken as 120 cm.$^{-1}$ for FeKα and 9.2 cm^{-1} for MoKα.

ELECTRONIC DISTRIBUTION NORMAL TO (001)

Integrated reflections and corresponding values of $F_{(00l)}$ for various orders of (001) are listed in Table 1. Probable signs of $F_{(00l)}$ given in the table were calculated on the basis of Gruner's structure with the further assumption that the water molecules are crystallographically equivalent and have $z=.208$. There is but little doubt, irrespective of poor absolute agreement between observed and calculated $F_{(00l)}$ values, that the signs are essentially correct since they chiefly are determined by the Mg and Si contributions.

Distribution of electrons[5] normal to (001) is given by

$$\rho(z)=\frac{1}{d}\sum_{-\infty}^{\infty}F_n\exp(-2\pi i\,nz)$$

$$=\frac{1}{d}[F_0+2F_2\cos 4\pi z+2F_4\cos 8\pi z+\cdots]$$

where $d=d_{(001)}$, z is the coordinate in the c direction, F_0 is the total number of electrons in the unit of structure, assumed to be 976, and $\rho(z)$ is

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[4] *J. Sci. Instrum.*, vol. **10**, p. 233–242, 1933.

[5] Compton, A. H., and Allison, S. L.: X-Rays in Theory and Experiment, p. 460, 2nd edition, *New York*, 1935.

TABLE 1. INTEGRATED REFLECTIONS AND CALCULATED F VALUES FOR (001) REFLECTIONS OF VERMICULITE, SAMPLE #5

Order	Integrated Reflection $\times 10^6$	Absolute F		
		Observed	Probable sign	Calculated
2	vs FeKα		+	256
4	vw			10
6	ms			68
8	62.0	161	+	145
10	80.0	222	+	304
12	3.6	54	−	97
14	11.0	106	−	105
16	3.2	62	−	92
18	3.2	67	+	106
20	12.0	137	+	198
22	2.7	65	+	100
24	6.9	97	+	158
26	0.3	18	+	50
28	7.5	69	+	84
30	2.4 MoKα	51	+	88
32	4.8	76	+	110
34	2.4	56	+	100
36	0.0	00		
38	0.5	28	−	64
52	1.0	48	+	145

the electron density at (z). Calculated values for the summation, omitting F_4, F_6, F_{36}, F_{38}, and F_{52} are shown in Fig. 1.

The electron distribution from 0.0 to 4.0Å resembles that found for muscovite[6] which also contains pyrophyllite-talc-like layers. An attempt was made to separate the distribution into several parts as shown in Fig. 1 by the dotted curve. Even though such a procedure is somewhat arbitrary it should lead to approximate values for the number of electrons associated with each peak. Results of this analysis are shown in Table 2.

Since individual peaks such as those at .000 and .038 of Fig. 1 are quite sharp the contributing atoms must be practically coplanar. Thus it follows that the talc layer, $(OH)_2Mg_3Si_4O_{10}$, must closely approach the ideal structure put forward by Pauling. The peak at $z = .208$ which corresponds to the water molecules between the pyrophyllite layers is also quite sharp. It would seem that the water molecules could not deviate by more than .2Å from a plane and that they are probably coplanar. Moreover, there are two or more water molecules in each layer, and two such layers are present between each talc layer.

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[6] Jackson, W. W., and West, J., *Zeits. Krist.*, vol. **76**, p. 215, 1930.

TABLE 2. ANALYSIS OF ELECTRON DISTRIBUTION NORMAL TO (001), SAMPLE #5

Coordinate	Probable Constituent	Total number of electrons	Number of electrons per atom
.000	5.5 Mg^{+2}, .5 Fe^{+3}	124	11.7
.038	3 O^{-2}, 3$(OH)^-$	63	10.5
.095	Al^{+3}, 3 Si^{+4}	41	10.2
.115	6 O^{-2}	55	9.2
.208	2 H_2O, 1.4$(OH)^-$	28	8.2
.250	0.7 Ni^{+2}	11	16

While the peak at .000 corresponding to the positions of the atoms with octahedral coordination is considerably greater than that at .095, which is formed by Al^{+3} and Si^{+4} in tetrahedral coordination, it is not sufficiently large to accommodate much replacement of Mg^{+2} by heavier atoms. It will later be shown that such replacement is also inconsistent with the chemical analysis. A Fourier analysis usually gives some spurious features and the small peaks near $z=.15$ and $z=.18$ are probably of this type. However, the peak at $z=.25$ is somewhat larger indicating that a few atoms might be in that position. This would be expected for a chlorite which is formed by combination of brucite-like layers with pyrophyllite-talc layers. Sample #5 is then probably a mixed chlorite-vermiculite, being predominantly vermiculite with about one layer of chlorite for seven layers of vermiculite.

Accurate structure factors cannot be calculated for a mixed layer crystal since the distribution of the chlorite layers is not known. Calculated $F_{(00l)}$ values of Table 1 are for an assumed $(OH)_2Mg_3Si_4O_{10}.4H_2O$ structure. Lack of closer agreement between observed and calculated absolute values arises in part from the mixed chlorite structure, but it chiefly seems to be due to the ignoring of extinction and the temperature factor.

Appearance of a moderately intense (00 52) reflection further serves to verify the atomic distribution along the normal to (001). All the atoms of the pyrophyllite layer give their maximum contributions to this reflection as also do any possible atoms with $z=.25$. The water molecules also give a positive contribution of $0.4\ nf\ H_2O$ to the structure where n is the number of water molecules in the unit of structure. This reflection was omitted from the Fourier analysis, since it could only cause a high frequency variation in the curve which would be enhanced by omission of other reflections, that although unobserved still might have moderate $F_{(00l)}$ values.

COMPOSITIONS OF THE VERMICULITES

Gruner[7] has tabulated the analyses of a number of vermiculites and has shown that their average composition can be represented as

$$22MgO.5Al_2O_3.Fe_2O_3.22SiO_2.40H_2O$$

which is similar to that found by Ross and Shannon.[8] In this formula Fe^{+2}, Ni^{+2}, and Ca^{+2} are considered as replacing Mg^{+2}. A true vermiculite is entirely free of potassium, and when potassium is present the resulting mineral is one in which mica layers are present, as Gruner has shown.

Since vermiculites consist of interleaved talc and water layers their compositions can be discussed on the basis of the talc formula, $(OH)_2Mg_3Si_4O_{10}$, with isomorphous replacements. The fundamental structural principle is that only Al^{+3} and Si^{+4} ions have tetrahedral coordination, there being four such positions, all of which must be filled, for each twelve oxygen and hydroxyl ions. Positions with octahedral coordination, later referred to as Σ octahedral, can be filled by Al^{+3}, Fe^{+3}, Ti^{+4}, Mg^{+2}, Ca^{+2}, Li^{+}, Na^{+}, Ni^{+2}, Fe^{+2} and they are limited to three for every four tetrahedral positions. As Al^{+3} replaces Si^{+4} in tetrahedral positions, O^{-2} can be replaced by $(OH)^{-}$.

Gruner's average formula reduces to

$$(OH)_3(Mg_{2.75}Fe_{.25}{}^{+3}(Al_{1.25}Si_{2.75})O_9.3.5H_2O.$$

However, if each analysis is considered separately 2.75 it immediately appears that in five of the seven samples, including sample #5, Σ octahedral is greater than three, as can be seen in Table 3. In some sam-

TABLE 3. MOLECULAR COMPOSITIONS OF SOME VERMICULITES

	1[1]	2	3	4	5	6	7	#3	#5
Σ Al and Si	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Mg	2.82	2.44	2.46	2.70	2.09	2.84	2.07	2.49	2.82
Fe^{+3}	0.24	0.45	0.27	0.68	0.15	0.16	0.16	0.29	0.20
Fe^{+2}	0.04	0.01	0.04	0.05	0.06	0.03	0.03	0.09	0.05
Ca	0.01	0.16	0.00	0.03	0.00	0.02	0.03	0.01	0.05
Ni	0.02				0.13	0.21	1.16	0.13	0.45
Σ Mg to Ni	3.13	3.06	2.77	3.46	2.43	3.26	3.45	3.01	3.57
Color	Clear pale yellow	Golden yellow	Yellow brown	Yellow brown	Green yellow	Green yellow	Apple green	Yellow green	Clear yellow green

[1] Samples 1 to 7 are listed by Gruner (*loc. cit.*), #3 and #5 by Ross, Shannon, and Gonyer (*loc. cit.*).

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[7] Gruner, J. W., *loc. cit.*

[8] *Am. Mineral.*, vol. **11**, p. 92, 1926.

ples, particularly 4, it is probable that impurities between the vermiculite plates enhance Σ octahedral, but this cannot possibly be the case for clear varieties such as 7 and #5.

A logical explanation for the apparent surplus of atoms with octahedral coordination is that they are partially present in brucite-like layers, $R_3^{+2}(OH)_6$, between the talc layers thus forming a chlorite-like structure, as also is indicated by the Fourier analysis and permitted by the observed densities. There is no reason why Σ octahedral cannot be less than three for a true vermiculite and for such samples it is possible that part of the aluminum has octahedral coordination.

ATOMIC DISTRIBUTION IN THE *a* AND *b* DIRECTIONS

Attention is now turned to the manner in which the talc-like layers are superimposed in the vermiculites. With Gruner it is found that reflections from (*hkl*) are present only if (*h*+*k*) is even, and from (*h*0*l*) if *h* and *l* are even. The space group, therefore, either must be $C2/c-C_{2h}^6$ or $Cc-C_s^4$, the former being assumed by Gruner.

TABLE 4. ATOMIC COORDINATES OF SOME POSSIBLE VERMICULITE STRUCTURES REFERRED TO GENERAL POSITIONS OF SPACE GROUP *Cc*

Atom	$x2'$	$x2$	$y=Y+$	z
Mg	0	0	0	0
Mg	0	0	1/3	0
Mg	0	0	2/3	0
(OH)	−.154	.180	1/2	.04
(OH)	.154	−.180	5/6	−.04
O	−.154	.180	5/6	.04
O	.154	−.180	1/2	−.04
O	−.154	.180	1/6	.04
O	.154	−.180	1/6	−.04
O	.117	−.048	3/4	.115
O	−.117	.048	7/12	−.115
O	−.382	.452	3/4	.115
O	.382	−.452	7/12	−.115
O	−.132	.202	0	.115
O	.132	−.202	1/3	−.115
Si	−.138	.196	5/6	.095
Si	.138	−.196	1/2	−.095
Si	.362	−.304	2/3	.095
Si	−.362	.304	2/3	−.095

Possible methods of superimposing talc-like layers are the same as those previously described for talc,[9] and for the sake of brevity it will be assumed that the other work is at hand. Atomic coordinates for structures 2 and 2′ are given in Table 4. For these the $(OH)_2Mg_3Si_4O_{10}$ layer has a center of symmetry and if the space group is $C2/c$, the translation Y is zero. Structures 2 and 2′ differ in that the upper $(Si_2O_5)_x$ sheet of an $(OH)_2Mg_3Si_4O_{10}$ layer is shifted by $+x$ or $-x$ with respect to the lower $(Si_2O_5)_x$ sheet. Gruner's structure corresponds to 2′ when his coordinates are referred to the correct monoclinic angle β. Structures 1 and 1′ are obtained if the centers of symmetry are between the silicate layers.

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[9] Hendricks, S. B , *Zeits. Krist.*, vol. A(99), pp. 264–274, 1938.

Reference to Table 5 shows that structures 1, 1′, and 2′ cannot possibly explain the observed intensities. Structure amplitudes were calculated, ignoring possible contributions of water molecules and chlorite layers. These structures, however, are safely eliminated even allowing for a maximum detrimental effect of the omitted atoms. Agreement between observed and calculated intensities for structure 2 is entirely satisfactory as can be seen in Tables 5 and 6. The structure can be accepted with confidence and only the possible arrangement along the y axis remains to be considered.

TABLE 5. CALCULATED F/8 VALUES OF SOME $(h0l)$ REFLECTIONS FOR POSSIBLE VERMICULITE STRUCTURES, CuKα

Values considered to be impossible are indicated by asterisks.

Plane	Observed Intensity Sample #5	Structure			
		1′	1	Gruner 2′	2
200	vw	−6	6	6	−6
202	ms	39	2*	24	−12
$20\bar{2}$	ms	15	35	−11	14
204	vw	−4	12*	35*	−4
$20\bar{4}$	s	31	−13	−13	30
206	m	13	−4*	28	15
$20\bar{6}$	vs	−7*	23	4*	37

Weissenberg goniometer photographs show that (hkl) reflections are diffuse unless k is a multiple of three. This is illustrated by the photographs of the equatorial zone and the first layer line about the a axis reproduced in Fig. 2. If k is a multiple of three the reflections are sharp and have intensities that can only be explained if the translation Y of Table 4 is a multiple of 1/6. It also is observed as was the case for talc that (hkl) reflections with $k=3n$ and l odd are absent which also requires $Y=n/6$.

Table 6. Calculated F/8 Values* and Estimated Intensities for Some ($h0l$) Reflections of Vermiculite, CuK Structure 2, Sample #5

l/h	$\bar{2}$		$\bar{4}$		$\bar{6}$		2		4		6	
0	vw	−6	mw	13	mw	19						
2	ms	14	mw	−13	m	24	ms	−12	m-ms	37	vvw	7
4	s	30	m	−13	w	16	vw	−4	m	24	vvw	1
6	vs	37	w	9	0	5	m	15	0	2	vvw	2
8	m	16	m	23	0	0	ms	18	vw	5	w	10
10	ms	10	w	−12	vw		w	8	mw	17	vw	
12	ms	15	0	−5	w		w	2	m	26	0	
14	s-ms	27	0	4	vw		m	18	w	13	w	
16	m-ms	23	mw	23	0		m-ms	30	0	−5		
18	0	0	mw	29			ms	30	0	−4		
20	w		mw				w		0			
22	vw		vw				0		vvw			
24	w		0				0		vvw			
26	mw		0				mw		vvw			
28	0		w				mw					
30	vw		w				0					

* Water molecules between layers were ignored in obtaining the calculated values.

Table 7. Calculated F/8 Values and Estimated Intensities for Some ($0kl$) Reflections of Vermiculite, CuKα Structure 2, Sample #5

l/h	2*	4*	6		8*	10*	12β[2]	
0	ms[1]	mw[1]	vs	35	vw[1]	w[1]	m	22
2			ms	25			mw	14
4	w	w	m	11			0	2
6	m	mw	0	0	0	0	0	−3
8	mw	vw	w	5	0	0	w	8
10	0	mw-w	m	15	0	0		
12	0	0	mw	11	0	0		
14	0	w	0	−3	0	0		
16	0	0	w	−9				
18	0	0	0	2				
20	0	0	w-mw	23				
22	0	0	mw-m	28				
24	0	0	mw	13				

* Reflections having these indices are lengthened and diffuse.

[1] These reflections are not sufficiently resolved for estimation of separate intensities.

[2] Intensities estimated for CuKβ line, all others are for CuKα.

Attempts to explain (02*l*) and (04*l*) intensities with a particular value of *n* were unsuccessful and there can be no doubt but that the vermiculites have the type of random structure along the *b* axis found for dickite,[10] talc,[9] and pyrophyllite.[9] This is a structure in which the various talc-like layers of the vermiculite structure would have random shifts of $n/6$ along the *b* axis. Such a structure should only give weak (*hkl*) reflections with $k \neq 3n$, as was observed to be the case. However, the reason for the diffuseness of these reflections is not very apparent although it is quite probably related to the random structure. A possible reason is that the absence of a regular periodicity in the structure for these planes is equivalent to a reduction of the lattice thickness. However, the consequences of an irregular structure have not been carefully thought through.

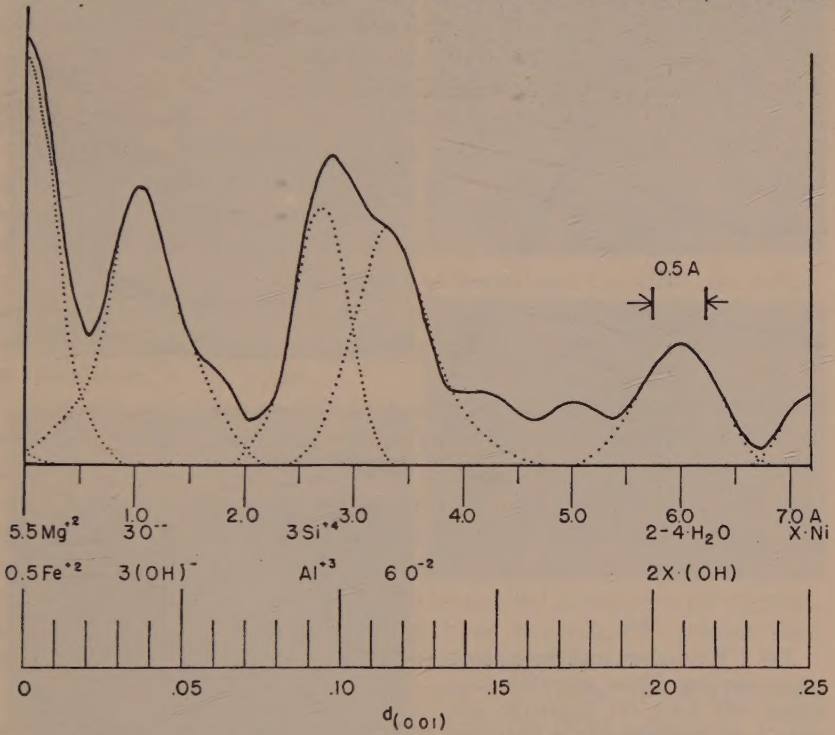

FIG. 1. Electronic distribution normal to (001) of vermiculite. This particular crystal contains some chlorite layers.

Atomic positions in neighboring silicate layers of a unit of structure have coordinates required by space group $Cc-C_s^4$. However, the positions along the *b* axis are not the same from one unit of structure to another and thus the space group is only a pseudo one.

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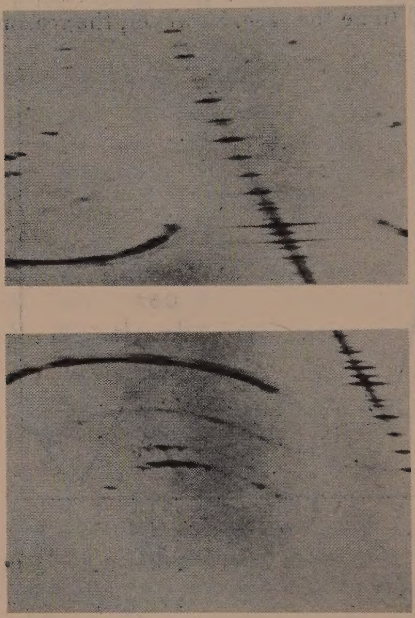
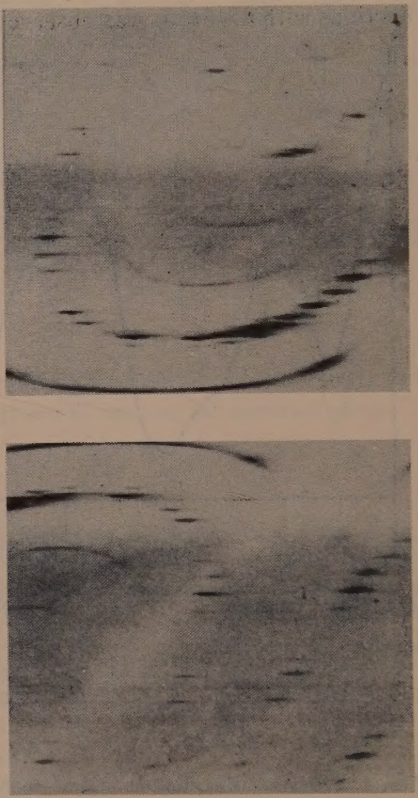
[10] Hendricks, S. B., *Am. Mineral.*, vol. **23**, pp. 295–302, 1938.

DISCUSSION

Consideration of possible arrangements of water molecules in the *a* and *b* directions is deferred to the following paper. They have but small effect on the intensities of (*hkl*) reflections and thus cannot be located by strict argument.



(a)



(b)

FIG. 2. Weissenberg goniometer photographs showing diffuse reflections from planes with $k \neq 3$. (a) Equatorial zone about *a* axis, specimen #3. (b) First layer line about *a* axis, specimen #5.

The muscovite, revised vermiculite, talc, pyrophyllite, and possibly the chlorite structures have the same type of relative shift of the $(Si_2O_5)_x$ sheets of the silicate layers. Oxygen atoms in the upper part of one talc-like layer and the bottom of another have nearly the same arrangement in projection on (001) for vermiculites and talc, even though they are separated by 7.8 and 2.8Å, respectively, in the two structures along the normal to (001). Figure 3 of the previous paper[9] on talc thus holds approximately for vermiculite, the relative shifts of the hexagons along the *a* axis being −0.21Å and +0.07Å, respectively. This figure also shows the probable translations of talc layers along the *b* axis of the vermiculite structure.

Random structures of the type found in dickite, pyrophyllite, talc, and the vermiculites possibly are present also in related minerals, such as the chlorites. However, before a general conclusion can be reached each case must be examined on the basis of as extensive data as can be obtained. Micas and brittle micas would not be expected to have such random structures, since the alkali or alkaline earth ions have twelve fold coordination which can only be met by one particular shift of the layers. The stability of the single configuration is enhanced by the electrostatic attraction due to the ions between the layers.

Chrysotile[11] also has some random type of structure along the *b* axis which requires further study. A closely analogous situation has been found for several compounds that form liquid crystals,[12] including parazoxyanisole, p-azoxyphenetol, cholesteryl chloride, and cholesteryl bromide. In these compounds, according to Bernal and Crowfoot, the diffuse reflections are from planes that are normal to the characteristic long direction of the molecules along which apparently there is some freedom of translation in the lattice.

It is not surprising to find that vermiculites form mixed structures with the chlorites and micas. In fact, any mixture of mica, vermiculite, chlorite, pyrophyllite, stilpnomelane (provided this is not a mixed structure) and talc layers would not be unreasonable. The list also might include kaolin and hydrated kaolin layers. The presence of vermiculite layers in macroscopic crystals can best be recognized by a swelling produced upon heating, which also might be applied to microscopic crystals. Mixed vermiculite-chlorites need not have Σ octahedral greater than three, and thus might be very difficult to recognize.

The intermingling of mica, pyrophyllite, talc, kaolin, or hydrate kaolin layers with vermiculite should greatly alter the (001) reflections. If the mixing is a random one the resulting effect would be similar to that discussed for montmorillonite in the following paper. This probably is the case for the mixed vermiculite-micas studied by Gruner, a condition which he rather recognized. Minerals of this type apparently are quite common in soils and Dr. Drosdoff of these laboratories has isolated several specimens. A sample of jefferisite from Brandon Quarry, the type locality, gave the usual vermiculite diffraction pattern which indicates that it is either a vermiculite or vermiculite-chlorite. Gruner previously had described similar material as vermiculite-mica, so it is apparent that considerable variation can be expected even in a restricted locality.

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[11] Warren, B. E., and Bragg, W. L., *Zeits. Krist.*, vol. **76**, pp. 201–210, 1930.

[12] Bernal, J. D., and Crowfoot, D., *Trans. Faraday Soc.*, vol. **29**, pp. 1032–1049, 1933.

SUMMARY

The crystal structure of vermiculites has been determined by use of x-ray diffraction data from single crystals. Lattice dimensions for the unit of structure are: $a=5.33$Å, $b=9.18$Å, $c=28.85$Å, and $\beta=93°\ 15'$. A Fourier analysis of the $(00l)$ reflections leading to the electron distribution normal to (001) verifies the structure previously advanced by Gruner insofar as it requires interleaving of layers containing water molecules with silicate layers similar to those of talc.

Vermiculites have the same type of shifts in the a direction as found in muscovite, talc, and pyrophyllite. They resemble the last two minerals and dickite in having a partially random superposition of structural layers along the b axis.

Many of the minerals previously described as vermiculites are mixed vermiculite-chlorites similar to the mixed vermiculite-micas described by Gruner.

NOTE. In carrying out the above analysis no attention was given to alternative choices of the c axis and it was assumed that the angle β as given by Gruner was somewhat in error due to the inherent difficulty of interpreting powder diffraction data. Actually the only difference is in the choice of the c axis and his structure corresponds to 2 above, instead of 2′, and the shift in the structure is different from that of mica. The index transformations are:

$$-h=h',\ k=k',\ l=h'+l^1$$

where the primes refer to the axes used by Gruner.

STRUCTURES OF KAOLIN AND TALC-PYROPHYLLITE HYDRATES AND THEIR BEARING ON WATER SORPTION OF THE CLAYS

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Clays as constituents of soils are of great interest in their influence on texture, water retention, and distribution of soil solutions. These properties are probably determined by the peculiar sorption of water by clays which is but little understood, although it must depend upon the structures of the constituent minerals. Increased knowledge of the crystal structures of minerals related to the micas now permits a first study of the problem.

Interest in montmorillonite as a constituent of many clays has focused attention upon its imbibition of water. Both it and the vermiculites are hydrates of pyrophyllite- or talc-like minerals in which water molecules are present between alumino-silicate layers. Hydrated halloysite seems to have a similar relationship to the kaolin structure. In the following work hypotheses are advanced to account for the structures of these hydrates and their bearing on the water sorption of the clay minerals.

Structure of Water Layers

Pauling[1] showed that a number of silicate minerals having micaceous cleavage possess the common structural element of tetrahedral SiO_4 groups joined by the sharing of oxygen ions at tetrahedron corners, into an extended hexagonal net having the composition $(Si_2O_5)_n$. These layers are combined with octahedral groupings of oxygen ions, common to SiO_4 groups, and hydroxyl ions about Mg^{+2}, Al^{+3}, and Fe^{+3} to form multiple layers, such as are found in pyrophyllites, talc, micas, and kaolin minerals. In chlorites[2] the multiple $((OH)_2Mg_3Si_4O_{10})_n$ layers of the talc structure are interleaved with neutral brucite layers, $Mg(OH)_2$, formed by octahedral coordination of hydroxyl ions about Mg^{+2}.[3]

It is here proposed that the hydrates of the silicate layer minerals related to the micas contain layers of water molecules joined into hexagonal groups of an extended hexagonal net. A layer of this type is shown in projection in Fig. 1. Its stability arises from the attraction between hydrogen atoms of water molecules and neighboring oxygen ions of the silicate layers, or oxygen atoms of other water molecules in the net.[4] The arrangement is partially a result of a tetrahedral distribution of charge about a water molecule; two corners of the tetrahedron being occupied by hydrogen atoms and the other two corners by an excess of electrons.[5] In the language of Bernal and Megaw, each side of the hexagon of Fig. 1 must correspond to a hydroxyl bond, the hydrogen-oxygen bond of one water molecule being directed toward the negative charge of a neighboring molecule. Since there are $3n/2$ sides for a net of n water molecules having $2n$ hydrogen atoms, one fourth the hydrogen atoms or hydrogen atoms of half the water molecules are not involved in binding within the net. These hydrogen atoms indicated at K, M, and O of Fig. 1 join the net to oxygen ions in the top of the neighboring silicate layer.

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[1] Pauling, L., *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 578–582, 123–129, 1930.

[2] McMurchy, R. C., *Zeits. Krist.*, vol. **88**, pp. 420–432, 1934.

[3] For a general discussion of the compositions and structures as well as drawings representing the structures of these minerals see W. L. Bragg, Atomic Structure of Minerals, pp. 203–229, *New York*, **1937.**

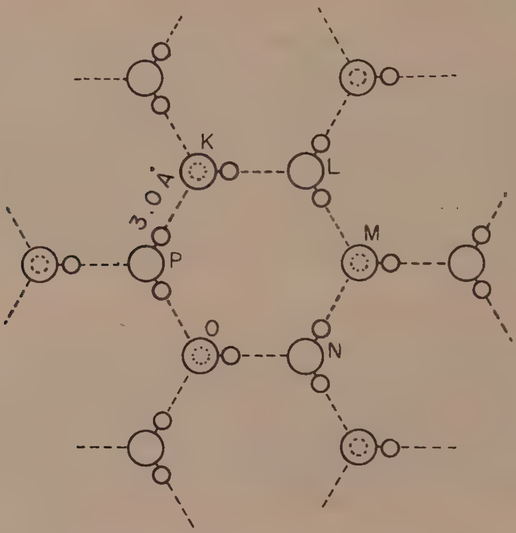

FIG. 1. Hexagonal net of water molecules. In this and the following figures large spheres represent oxygen atoms and small spheres hydrogen atoms; dotted lines indicate bonding through hydrogen.

The distribution of hydrogen atoms along the sides of hexagons shown in Fig. 1 is but one of many possible arrangements. In it the hydrogen atoms can be in positions required by space group *Cm* or *Cc* without increasing the size of the unit of structure required by the silicate framework. If the separation of the oxygen atoms of the water molecules is about 3.0Å in projection, then the net has just the *a* and *b* dimensions of the silicate layer minerals. This distance is somewhat greater than 2.74Å, the separation of oxygen atoms in ice.

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[4] The general discussion of the role of hydrogen in crystal structure as presented by Bernal, J. D., and Megaw, H. D., *Proc. Roy. Soc.* (*London*), vol. **A 151**, pp. 384–420, 1935, is applicable to this work.

[5] The tetrahedral character of the water molecule has been discussed by Bernal, J. D., and Fowler, A. H., *Jour. Chem. Phys.*, vol. **1**, pp. 515–548, 1933.

A similar hexagonal arrangement of water molecules is present in acetaldehyde-ammonia,[6] $CH_3COH \cdot NH_3$, which is a hydrate, $(CH_3 \cdot CHN)_3 \cdot 3H_2O$. In this compound the separation of the water molecules is 3.0Å. Six water molecules forming a hexagon in projection do not lie in one plane but so alternate with the symmetry of the point group $\bar{3}$ as to preserve a regular tetrahedral distribution of bonds to oxygen atoms. Boric acid[7] also contains similar hexagonal rings formed by six (OH) groups, the separation of the oxygen atoms being 2.71Å. In boric acid, however, the proton might be equidistant from two oxygen ions.

In the remainder of the work it will be assumed that the oxygen atoms are in one plane, there being considerable evidence in favor of such an assumption. Displacement from a plane similar to that of $(CH_3 \cdot CHN)_3 \cdot 3H_2O$, would increase the separation of the oxygen atoms, which already are rather far apart, for binding through hydrogen. Even though the oxygen atoms are coplanar the hydrogen atoms of the hexagonal net need not be in the plane of the oxygen atoms but rather are displaced from it.

ARRANGEMENT OF WATER MOLECULES IN VERMICULITES AND WATER SORPTION ON THE SURFACES OF CLAY MINERALS

The atomic arrangement parallel to the micaceous cleavage, (00*l*), of vermiculite as derived in the preceding paper is shown in Fig. 2. In agreement with Gruner[8] it was found that the structure is formed of talc-like multiple layers with water molecules between the layers. Analyses, as listed by Gruner, indicate that eight water molecules at the maximum must be fitted into the space in the unit of structure between the silicate layers. This corresponds to two layers of four molecules each, which is the number required by the arrangement shown in Fig. 1. Moreover, the Fourier analysis of the (00*l*) reflections indicates that the oxygen atoms of the water molecules are probably coplanar.

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[6] Moerman, N. F., *Zeits. Krist.*, vol. **98**, pp. 447–455, 1938.

[7] Zachariasen, W. H., *Zeits. Krist.*, vol. **88**, pp. 150–161, 1934.

[8] Gruner, J. W., *Am. Mineral.*, vol. **19**, pp. 557–575, 1934.

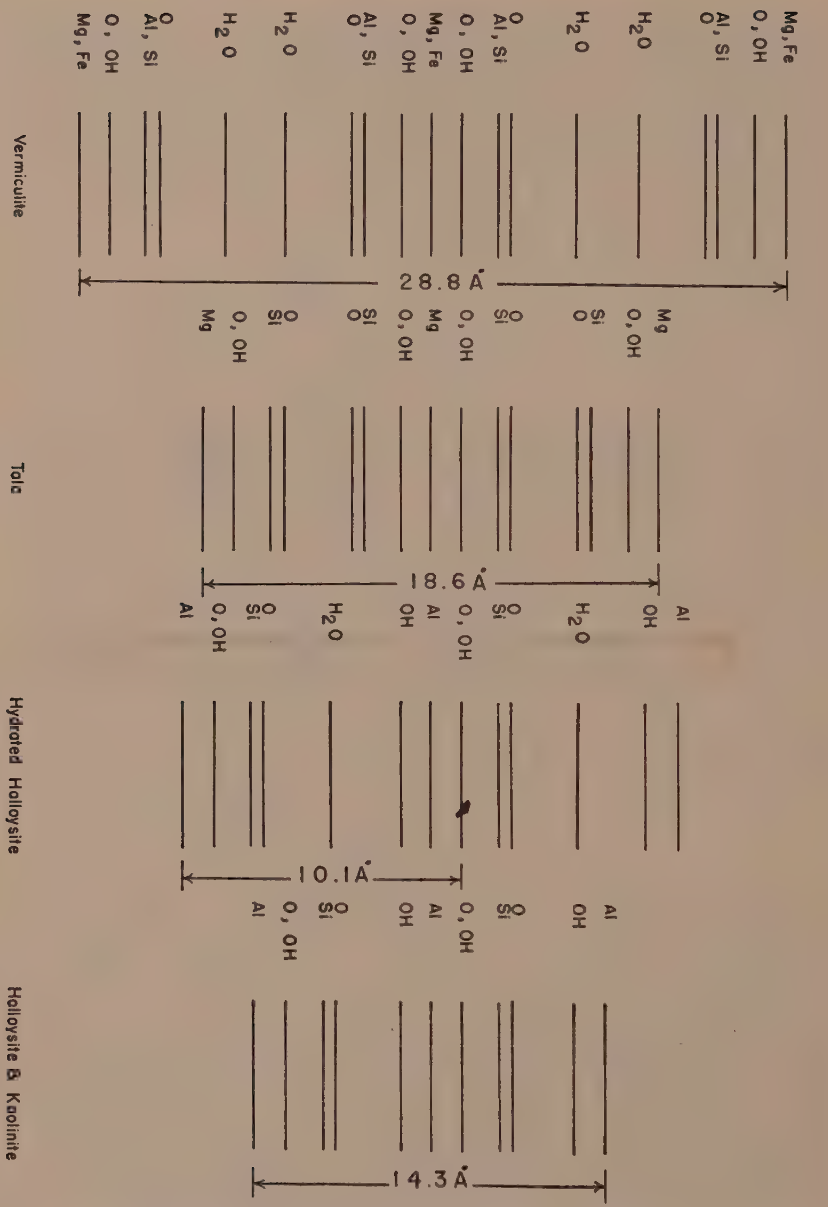

FIG. 2. Atomic arrangement parallel to (001) in some of the minerals related to the clays.

A possible manner of superimposing the net of water molecules upon the talc-like alumino-silicate layers of vermiculite is shown in Fig. 3. The exact manner of doing this was not found in the preceding work since it was possible to explain approximately the intensities of reflections without considering water molecules. However, absence of (*hkl*) reflections with *l* odd and *k* a multiple of three lends further support to the hexagonal framework structure in that it too would require them to be absent. A third of the oxygen ions in the top of a talc layer, or one crystallographically equivalent set, have neighboring water molecules. Superposition of the water molecules upon oxygen ions at *B* or *C* gives equivalent structures as far as the oxygen ions are concerned, and the actual structure might be one in which these three methods of superposition are randomly mixed.

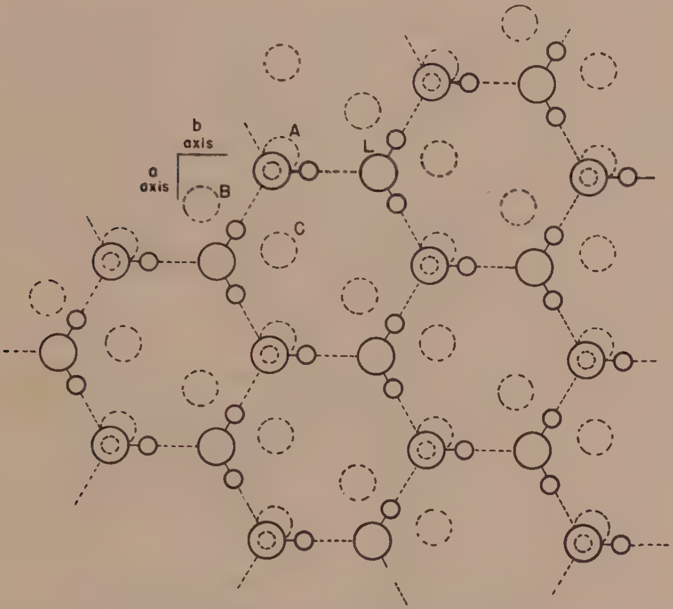

FIG. 3. Combination of water and vermiculite layers by binding through hydrogen. The oxygen atoms represented by large dotted circles are 2.73Å below the plane of the water molecules.

Water molecules would be expected to form similar layers on the surfaces of clay minerals, and could be held in other layers after the manner of Fig. 4. It is for this structural reason that water is unique in many sorptive properties of the clays, such as swelling of montmorillonite. Other hydroxylic compounds would, by the same binding, be expected to show preferential adsorption on surfaces containing oxygen ions. However, the adsorbed layer, in general, would not be expected to have a regular transverse structure.

In general, the same forces causing condensation of a vapor to a liquid are responsible for multimolecular adsorption[9] on the surface of a solid, and thus such layers appear to a considerable extent only near the saturation pressure. Expressed in another manner, a second layer of adsorbed nitrogen on the surface of mica is held by approximately the same forces as the surface layer of liquid nitrogen.

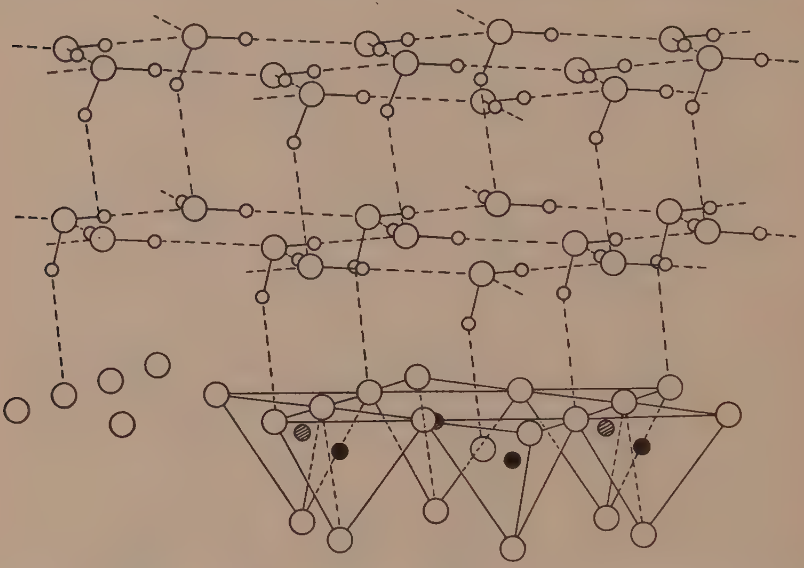

Fig. 4. Probable structure of multiple water layers on the surfaces of clays. Small black or shaded circles represent silicon atoms.

A network of water molecules like that of Fig. 1 would not be the stable configuration in liquid water where tetrahedral coordination is satisfied in other ways. However, if some force establishes such a structure, it in turn would be expected to cause surrounding molecules to take up the same structure. Formation of this type of layer at less than saturation pressures on the surfaces of silicate layer minerals shows that it is the more stable surface configuration. Stability of the layer arises from its geometrical relationship to oxygen ions of the silicate framework, after the manner of Fig. 3. Presence of the first layer still favors formation of a second, and the structure is thus propagated away from the surface. The dissociation pressure of successive layers considered as hydrates would finally approach the vapor pressure of water at the temperature of observation.

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[9] Brunauer, S., Emmett, P. H., and Teller, E., *Jour. Am. Chem. Soc.*, vol. **60**, pp. 309–319, 1938.

Both layers of water molecules between two talc-like layers of vermiculite would be expected to have similar relationships to oxygen ions of neighboring silicate layers. However, sufficient doubt exists about the details of the arrangement to leave considerable freedom in the choice of relative positions of water molecules in the two layers. For this reason the remainder of the drawings are merely schematic, indicating the type of bonding expected.

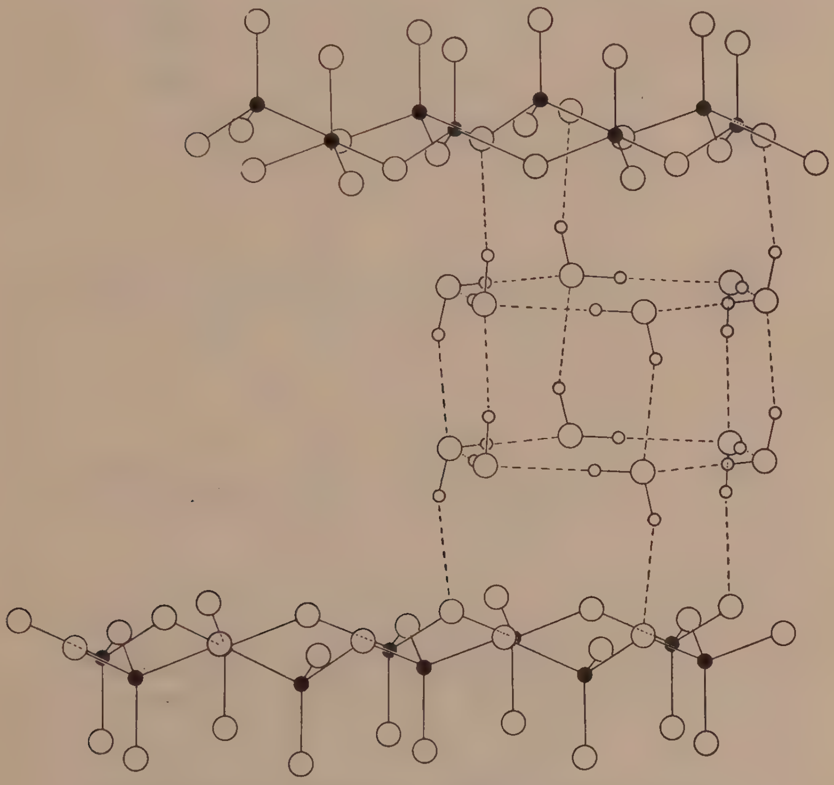

FIG. 5. Combined water layers in partially dehydrated vermiculite.

Gruner showed that as much as one half of the water can be driven off without changing the structure of vermiculite and that the water content is seldom as high as sixteen molecules for the unit of structure. The hexagonal nets of water molecules thus are not complete and as a consequence hydrogen atoms are free for binding between the water layers. Even for complete layers there is probably some interlayer binding by hydrogen atoms of water molecules such as *L* of Figs. 1 and 3. Water molecules of separate layers, therefore, might be expected to pack together, preserving tetrahderal coordination.

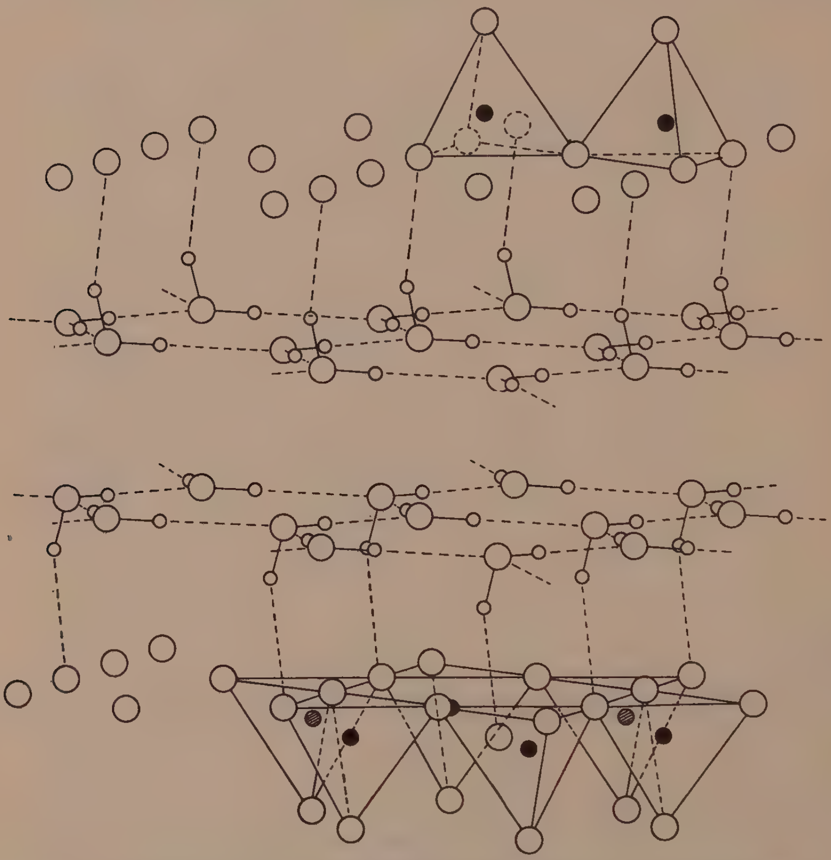

FIG. 6. A portion of the vermiculite structure showing layers of water molecules.

A vermiculite containing only 8 water molecules in the unit of structure according to these concepts would have the schematic structure shown in Fig. 5. The energy of binding between the talc layers would be expected to be greater than that of completely hydrated vermiculite shown in Fig. 6, since there is the same number of bonds to each water molecule but more bonds between the water layers.

ARRANGEMENT OF WATER MOLECULES IN HYDRATED HALLOYSITE

Hydrated halloysite has been shown to have the composition $Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$[10] and to be formed by superposition of neutral $((OH)_4Si_2Al_2O_5)_n$ layers, as present in the kaolin minerals, and layers of water molecules.[11] Its relationship to kaolin is somewhat analogous to that between vermiculite and talc. However, it differs in that there is only one layer of water molecules between the alumino-silicate layers corresponding to four water molecules in the unit of structure. Water molecules present in the layers can be expelled by drying at 50° and the mineral has not yet been rehydrated in the laboratory.[10,12]

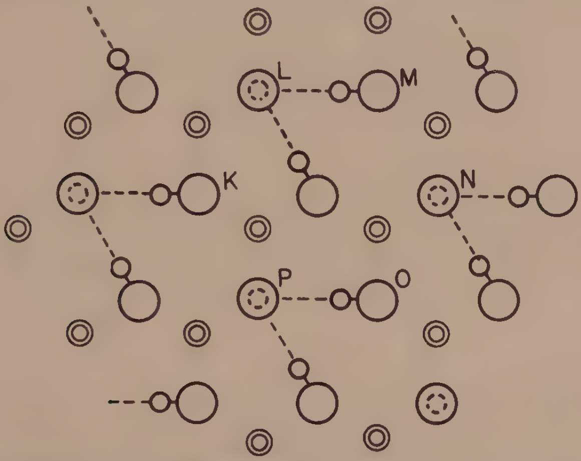

FIG. 7. The probable type of binding between hydroxyl groups in the $((OH)_4Al_2Si_2O_5)n$ layers of the kaolin minerals. Aluminum atoms, shown by double circles, are about 1.1Å above the plane of the hydroxyl groups.

The arrangement of oxygen ions in one side of a kaolin layer is the same as in the top of a talc layer; thus the structures shown in Figs. 1, 3, and 4 hold equally well for halloysite. The other side of a kaolin layer, however, contains only hydroxyl groups, and these in part are free for binding through hydrogen to oxygen atoms in the water layer. Part of the hydroxyl groups are involved in binding within the alumino-silicate layer, probably in a manner similar to that described for hydrargillite by Bernal and Megaw (*loc. cit.*). The principle of the arrangement is that hydrogen atoms should be as far as possible from aluminum ions consistent with the requirements of binding to other hydroxyl groups. This is accomplished for a kaolin layer after the manner shown in Fig. 7.

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[10] Hofmann, U., Endell, K., and Wilm, D., *Angew. Chem.*, vol. **47**, p. 539, 1934.

[11] Hendricks, S. B., *Am. Mineral.*, vol. **23**, pp. 295–301, 1938.

[12] Note Mehmel, M., *Fort. d. Mineral., Krist., u. Petro.*, vol. **21**, p. 80, 1937; *Chemie d. Erde*, vol. **11**, p. 1, 1937.

Hydrogen atoms of hydroxyl groups at *L*, *N*, and *P* of Fig. 7 are free for binding to oxygen atoms *L*, *N*, and *P* of water molecules in a layer of the type shown in Fig. 1. Each water molecule of the layer would be bound through hydrogen to four other oxygen atoms. The complete structure is schematically shown in Fig. 8.

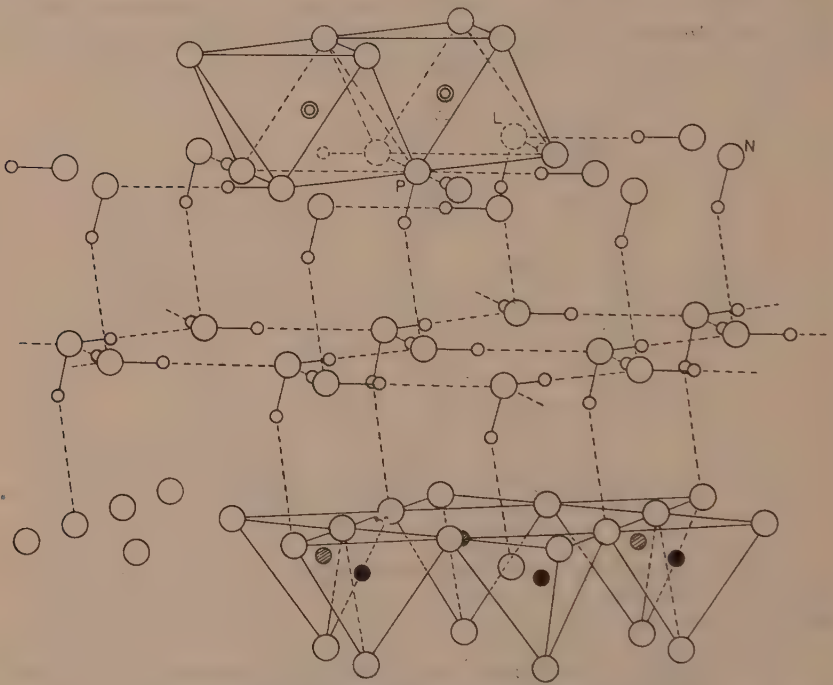

Fig. 8.-A portion of the hydrated halloysite structure showing a single layer of water molecules.

Possibility of binding through the hydroxyl ions is apparently the factor that limits the water molecules to a single layer. If these are expelled by heating, the structure collapses to the ordinary type found for the kaolin minerals in which the hydroxyl groups give binding directly to oxygen ions of the adjacent alumino-silicate layer. This structure would probably be more stable than that of the hydrate since the heat of formation of each hydroxyl bond would be expected to exceed that of a bond formed by hydrogen atoms of a water molecule, being more ionic in character. Ease of dehydration and failure of reversible hydration thus are quite reasonable.

HYDRATION OF MONTMORILLONITE

Much attention has been devoted to the swelling of montmorillonite. Hofmann, Endell, and Wilm[13] were the first to show that the imbibition of water is accompanied by an increase in the (001) spacing. They studied the change of spacing with water content and advanced the explanation that molecules are introduced between the talc-pyrophyllite layers. Maegdefrau and Hofmann[14] have studied the structure of montmorillonite in more detail and have concluded that the spacing varies continuously as a function of water content. A similar conclusion was reached by Nagelschmidt.[15] Bradley, Grim, and Clark[16] on the other hand found evidence for definite hydrates corresponding to certain (001) spacings. All of these workers agree that the water content approaches the amount required for close packing, which is six molecules for each layer in the unit of structure.

There are many difficulties in accepting these interpretations. Montmorillonite cyrstals are very thin and have a great amount of surface for water sorption. The analyses thus cannot give the amount of water between the layers. This is particularly true for the more hydrous specimens that can only be prepared by drying wet samples. Moreover, no hydrate structure has yet been found in which water molecules have close packed arrangements.

Even though some of the x-ray measurements seem to indicate that the separation of talc-pyrophyllite layers varies continuously with water content, closer analysis shows that this is neither required, nor in fact probable. Consider the diffraction of a parallel beam of radiation from a random stacking of plates.[17] The wave motion at P, Fig. 9, is given by

$$E_p = \frac{E_0 F e^2}{m_0 \rho c^2} \left[\sum_m \text{exp.}\, [2\pi i/\lambda][m\bar{d} + \bar{w}_m] \cdot [\bar{S} - \bar{S}_0] \right] \exp\, [2\pi i/\lambda]\, [ct - \rho]$$

where F is the structure for the plane and $[m\bar{d} + \bar{w}_m] \cdot [\bar{S} - \bar{S}_0]$ gives the path difference for rays scattered from various planes. The amplitude of the scattered wave will be:

$$E \sim \sum_m \exp\, [2\pi i/\lambda]\, [m\bar{d} + \bar{w}_m] \cdot [\bar{S} - \bar{S}_0]$$

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[13] *Zeits. Krist.*, vol. **86**, pp. 340–348, 1933.

[14] *Zeits. Krist.*, vol. **98**, pp. 299–324, 1937.

[15] *Zeits. Krist.*, vol. **93**, pp. 481–487, 1936.

[16] *Zeits. Krist.*, vol. **97**, pp. 216–222, 1937.

[17] The treatment given here is based upon that of Compton, A. H., and Allison, S. K., X-Rays in Theory and Experiment, p. 406 ff., *New York*, **1935**.

and the intensity:

$$I \sim \left[\sum_m \cos\frac{2\pi}{\lambda}[m\bar{d}+\bar{w}_m]\cdot[\bar{S}-\bar{S}_0]\right]^2 + \left[\sum_m \sin\frac{2\pi}{\lambda}[m\bar{d}+\bar{w}_m]\cdot[\bar{S}-\bar{S}_0]\right]^2$$

If the crystal is thick and the separations of the planes have a random variation, then the observed spacing would be near the average value, $d+w_m/m$. A second case is a restricted lattice, say of the order of ten layers thick, but with random distribution within a number of lattices.

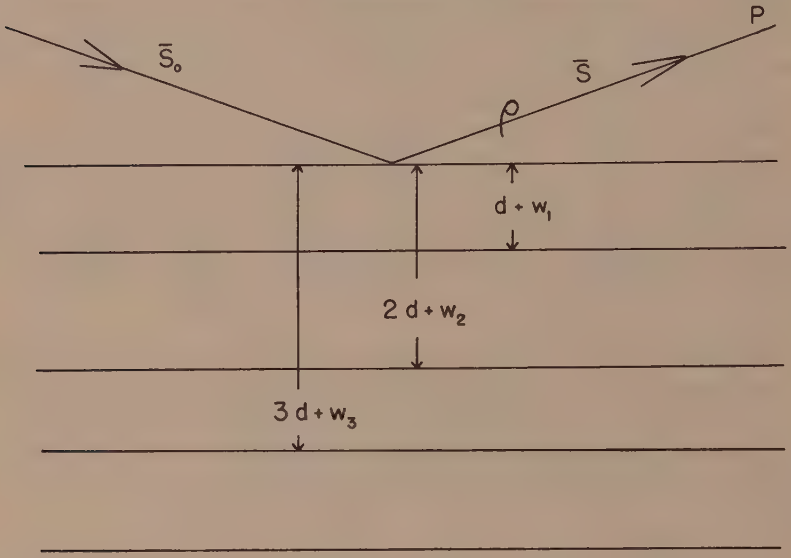

FIG. 9. *X*-ray diffraction from a random stacking of planes.

Again the average value will be observed but the reflections will be broader since they will be formed by summation of intensities from separate lattices.

That reflection will be sharp for which $w_m/\lambda\cdot[\bar{S}-\bar{S}_0]$ is any integer. Thus with montmorillonite there is always one high order of reflection present, (003) to (007), depending upon the hydration, with a spacing of about 3.0Å, which is usually sharp and intense. This is just the expected additional spacing required for a layer of water molecules. The reflection would appear sharp even though the number of layers of water molecules varied within a crystal giving some intermediate apparent spacing.

High order interference maxima would not be obtained for a lattice of this type and this is observed to be the case for montmorillonite. The situation is quite analogous to a solid solution between two hydrocarbons such as $C_{29}H_{60}$ and $C_{31}H_{64}$[18] which give an average spacing, but very few orders of reflection from (001) as compared with the pure hydrocarbons.

It thus is not inconsistent with any of the experimental data so far obtained for water molecules in montmorillonite to be present in layers of the type shown in Fig. 1. The structure is similar to that of vermiculite, Fig. 6, except that additional water layers can be reversibly added between the talc-pyrophyllite layers. This difference in behavior is partially a result of the very small particle size of montmorillonite which makes the total cohesive force per layer sufficiently small as to be overcome by molecular forces. A prosaic analogy would be the comparative ease of splitting a shingle as compared with a log. However, it also probably depends upon the presence of ions external to the talc-pyrophyllite layers that account for the base exchange of the mineral.

SUMMARY

Vermiculites, montmorillonite, and hydrated halloysite contain layers of water molecules joined into extended hexagonal nets of the type shown in Fig. 1. The peculiar water sorptive properties of clays are considered to arise from the formation of successive layers of this type over the surfaces.

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[18] Piper, S. H., Chibnall, A. C., Hopkins, S. J., Pollard, H., Smith, J. A. B., and Williams, E. F., *Biochemical Journal*, vol. **25**, p. 2084, 1931.

AN UNUSUAL FORM OF THAUMASITE FROM THE DUCKTOWN DISTRICT, TENNESSEE*

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U. S. Geological Survey, Washington, D. C.

Occurrence

An unusual occurrence of thaumasite, $CaSiO_3 \cdot CaSO_4 \cdot CaCO_3 \cdot 15H_2O$, was found by Mr. V. L. Kegler[1] in the Isabella mine, Isabella, Ducktown district, Tenn. The mineral was first noted as small tuffs of radiating crystals on the iron sulphides and was identified as thaumasite by Dr. C. S. Ross of the U. S. Geological Survey. It occurs in seams or vug-like cavities in the sulphides, 200 feet below the zone of secondary enrichment and seems to be associated with small surface-water channels which penetrate the primary ores, dominantly pyrrhotite with minor quantities of pyrite, chalcopyrite, sphalerite, and magnetite. Most of the thausmasite forms small patches of white needle-like crystals but one specimen (presented by Mr. Kegler to the U. S. National Museum),

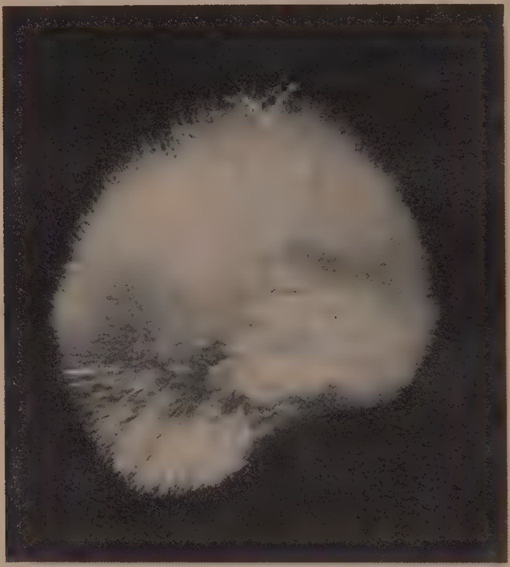

Fig. 1. Spherulitic group of thaumasite crystals from Ducktown, Tenn. Enlarged two diameters.

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* Published by permission of the Director, U. S. Geological Survey.

[1] Until recently mine superintendent of the Ducktown Chemical and Iron Company, Isabella, Tenn.

shown enlarged two diameters in figure 1, consists of a spherulitic group of very thin crystals radiating from a center of more massive material. The specimen resembles a zeolitic mineral much more than it does the thaumasite from Paterson, N. J., which is either compact massive, or in stubby crystals, usually only a few times as long as thick.

The individual crystals of the specimen shown in figure 1 are about a centimeter long and have an average thickness of only 0.04 (varying from 0.03 to 0.045) millimeters, a little thinner than a human hair. The ratio of length to thickness is about 250:1.

CRYSTALLOGRAPHY

Many of the crystals are terminated by the base $c\{0001\}$ and the pyramid of the first order $e\{10\bar{1}2\}$. The prism $m\{10\bar{1}0\}$ is the only other form identified. The terminal forms are about of equal size with the base slightly predominating.

The measurements for $e\{10\bar{1}2\}$ are as follows:

Measured		*Calculated*	
ϕ	ρ	ϕ	ρ
0°52′	29°42′	0°00′	28°16′
1 52	28 47		
0 02	28 47		
1 30	28 31		

The form $e\{10\bar{1}2\}$ was first identified on crystals from West Paterson, N. J., by Wherry.[2] The terminated crystals from the same locality earlier described by the writer[3] also had minute faces of a form whose ρ angle varied between 31° and 32°. No indices were assigned to this form but on the basis of Wherry's measurements the form is $e\{10\bar{1}2\}$. Wherry lists the forms c, m, a, e, p, $f\{20\bar{2}3\}$, and $q\{30\bar{3}2\}$. Crystals from Sweden and from Crestmore, Calif., showed only the three forms c, m, and p.

The best crystallographic data are those of Wherry who gives $(0001) \wedge (10\bar{1}1) = 47°05'$, $c = 0.931$, determined on thaumasite crystals from West Paterson, N. J. Flink[4] obtained a similar value, namely 47°35′, whence $c = 0.9479$, on thaumasite from Långbanshyttan, Sweden.

OPTICAL PROPERTIES

The indices of refraction of the thaumasite from Ducktown were determined as $\epsilon = 1.468$, $\omega = 1.506$. Determinations of the indices of refraction of this mineral from different localities show a constant value, as is to be expected from the remarkable constancy of chemical composition of thaumasite, as evidenced by the several chemical analyses in the literature.

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[2] Wherry, E. T., Notes on mimetite, thaumasite, and wavellite: *U. S. Nat. Museum Proceed.*, vol. **54**, p. 377, 1919.

[3] Schaller, W. T., The crystallography of thaumasite: *U. S. Geol. Survey, Bull.* **610**, pp. 131–132, 1916.

[4] Flink, Gustave, Einige Neuigkeiten in schwedischer Mineralogie. 4. Thaumasit: *Geol. Fören. Förh.*, vol. **39**, pp. 447–452, 1917.

INDICES OF REFRACTION OF THAUMASITE[5]

	ϵ	ω	B
Sweden (Bertrand)	1.467	1.503	.036
Sweden (Lévy & Lacroix)	1.468	1.507	.039
Utah (Butler)	1.464+	1.500+	.036
New Jersey (Brown)	1.468	1.505	.037
New Mexico	1.47	1.51	.04
Virginia	—	1.505	—
Ducktown	1.468	1.506	.038
Av.	1.468	1.506	.038

In its constancy of chemical composition, notwithstanding the presence of three acid radicles, thaumasite differs from the varying composition of the similar more complex wilkeite group in which P_2O_5 is a fourth acid radicle.[6]

LOCALITIES AND ORIGIN

A mineral of such an unusual composition as thaumasite might be expected to form only under very unusual conditions and hence to be of extremely rare occurrence. Although it is known only from Sweden and the United States, there are 12 localities where it has been found. Four localities are known in Sweden; the Bjelkes mine near Åreskutan; Kjoland in Kalls Kirchspiel, Jemtland; Skottvång in Södermanland; and Långbanshyttan.

It has been found in six States in the United States, as follows:

New Jersey—West Paterson and Great Notch
Virginia—Leesburg

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[5] Thaumasite (easily available from Paterson, N. J.) is excellent material for student practice. Four student determinations gave:

ϵ	ω
1.468	1.508
1.465	1.508
1.462	1.506
1.468	1.506

Thaumasite has no basal cleavage and hence it is difficult (and good practice) for a student to obtain a fragment nearly parallel to the base which will show the uniaxial interference figure.

[6] McConnell, Duncan, The substitution of SiO_4- and SO_4- groups for PO_4- groups in the structure of apatite; ellestadite, the end-member: *Am. Mineral.*, vol. **22**, pp. 977–986, 1937.

Tennessee—Ducktown
New Mexico—Magdalena
Utah—Beaver County
California—Riverside and San Bernardino counties

When the origin of the thaumasite from West Paterson, N. J., became known through the discovery of anhydrite[7] and gypsum as its source material, Wherry[8] was justifiedly led to regard thaumasite, systematically, as a sulphate rather than as a silicate, a conclusion with which Holden concurred.[9] Later discoveries of thaumasite at other localities and under different geological environments, raise doubts as to whether it should be so considered.

At three of the American localities it occurs with limestone or dolomite in which no sulphate mineral other than thaumasite is reported. In Utah, thaumasite forms a network of small veins in the contact-altered limestone on the first level, about 80 feet below the surface in the Old Hickory mine in Beaver County.[10] In San Bernardino County, California, thaumasite forms narrow veins in metamorphosed dolomite.[11] Thaumasite forms a felted crust of silky fibers on some of the metamorphosed limestone northeast of Oak Spring, Magdalena district, Socorro County, New Mexico.[12]

At Leesburg, Virginia, thaumasite was found[13] in xonotlite which forms thin seams in relatively unaltered limestone. At Crestmore, Riverside County, California, thaumasite[14] was derived from spurrite, a carbonate-silicate of calcium, by the action of sulphated waters. Later examination showed[15] that merwinite, gehlenite, diopside, and wollastonite—all silicates—are intimately associated with the spurrite.

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[7] Allen, F. I., The origin of thaumasite: *Am. Jour. Sci.*, 4th ser., vol. **39**, p. 134, 1915. See also Schaller, W. T., The crystal cavities of the New Jersey zeolite region: *U. S. Geol Survey, Bull.* **832**, pp. 35–36, 38–40, (pls. 12, B; 15, and 16), 1932.

[8] Wherry, *op. cit.*, pp. 378–379.

[9] Holden, E. F., A study of the constitution of thaumasite: *Am. Mineral.*, vol. **7**, p. 14, 1922.

[10] Butler, B. S., and Schaller, W. T., Thausmasite from Beaver County, Utah: *Am. Jour. Sci.*, 4th ser., vol. **31**, pp. 131–134, 1911.

[11] Schaller, W. T., Monticellite from San Bernardino County, California, and the monticellite series: *Am. Mineral.*, vol. **20**, p. 816, 1935.

[12] Statement taken by permission of G. F. Loughlin from manuscript of unpublished report: Geology and ore deposits of Magdalena district, N. Mex., by G. F. Loughlin and A. H. Koschmann.

[13] Shannon, E. V., Mineralogy and petrography of Triassic limestone conglomerate metamorphosed by intrusive diabase at Leesburg, Virginia: *U. S. Nat. Museum Proceed.*, vol. **66**, Article 28, p. 13, 1925.

[14] Foshag, W. F., Thaumasite and spurrite from Crestmore, California: *Am. Mineral.*, vol. **5**, pp. 80–81, 1920.

[15] Larsen, E. S., and Foshag, W. F., Merwinite, a new calcium magnesium orthosilicate from Crestmore, California: *Am. Mineral.*, vol. **6**, p. 147, 1921.

The two localities in New Jersey are the only American localities in which it can be shown that the thaumasite was derived from a sulphate mineral. As it evidently can be derived from either a carbonate, carbonate-silicate, or silicate mineral, its placement as a sulphate rather than a silicate, on the basis of its origin in New Jersey, seems questionable. The Ducktown occurrence gives no direct clue to any parent mineral and its deposit on iron sulphide suggests that it formed from commingling waters containing the necessary constituents, rather than directly from some pre-exsiting calcium mineral.

NOTE. An occurrence of 1–5 mm. wide veins of thaumasite ($\omega = 1.507$, $\epsilon = 1.468$) in a metamorphosed inclusion of marl in basalt from Hungary has recently been described by Mauritz.[16] This is an additional occurrence of thaumasite not derived from a pre-existing sulphate mineral.

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[16] Mauritz, B., Die Mineralien in den Hohlraümen der Basalte von Haláp und Gulács im Plattenseegebiete (Ungarn): *Mineral. Petrogr. Mitteil.* (*Zeits. Krist., Mineral., Petrogr., Abt. B*), vol. **50,** (heft 2), pp. 94–95, 1938.

TARBUTTITE

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Introduction

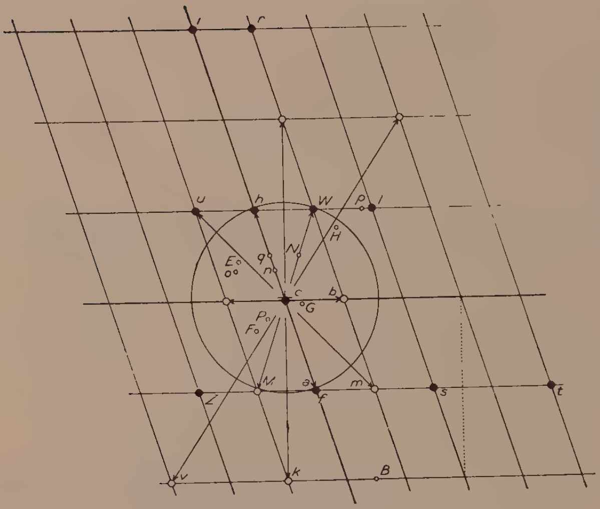
Tarbuttite, a basic zinc phosphate, was first described by Spencer (1907, 1908). His crystals were for the most part composed of subparallel groups with individual forms usually striated and rounded, with few well-defined faces in the primary zones so that, to use his own words, "the calculations are all the more awkward . . . and the elements given below can only be considered as a first approximation." Rosický (1913) adopted Spencer's setting and measured a large number of crystals on which he found 17 new forms but did not recalculate the elements.

The stereographic projection accompanying Spencer's paper shows a large obliquity of the base, a scarcity of forms in the vertical zone and several form-rich pyramidal zones. These facts suggested a search for a possible better choice of elements. To this end a complete morphological investigation together with an x-ray determination of the lattice constants was undertaken, the results of which appear in this paper.

Morphology

A number of matrix specimens of tarbuttite from the type locality, Broken Hill mines, N. W. Rhodesia, now in the Harvard Mineralogical Museum, were carefully examined for suitable crystals. One superb specimen (Harvard number 92882) was found consisting of a matrix of black stalactitic limonite thickly sprinkled with a large number of colorless, transparent crystals varying in size from 0.1 to 1.0 millimeter. The faces were bright, sharp and free from striations. Their habit, short prismatic approaching pseudoisometric, presented considerable difficulty in the choice of the prismatic zone.

The crystals are usually attached to the matrix on a plane nearly parallel to the perfect cleavage. The choice of a prismatic zone was made difficult in these crystals through the absence of a pronounced direction of elongation and by the presence of large faces of what proved to be forms of highly complex indices (forms G and E of figure 2). But by setting the perfect cleavage ({001} of Spencer's position) vertical and by selecting the strongest zone of which it formed a part as the prism zone, a satisfactory orientation was secured. Measurements being made on the two-circle goniometer with this zone vertical, a gnomonic projection was obtained which is shown in figure 1. In this projection the choice of b[010] normal to the cleavage is obvious. For a[100] the selec-


r
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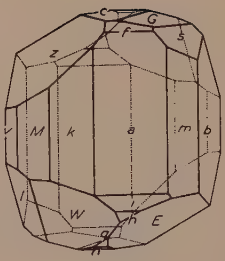
1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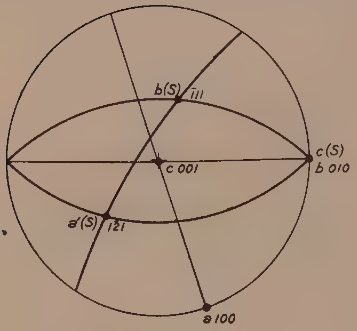
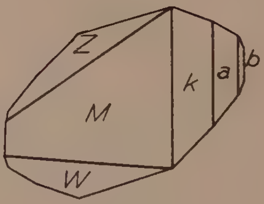
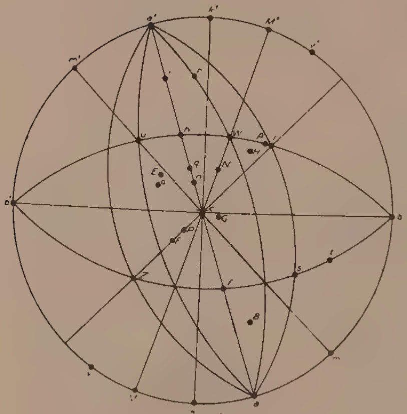
2


b(S) 111
c(S)
c 001
b 010
a(S) 121
a 100

3


Z
M
k
a
b
W

2a


a'
k'
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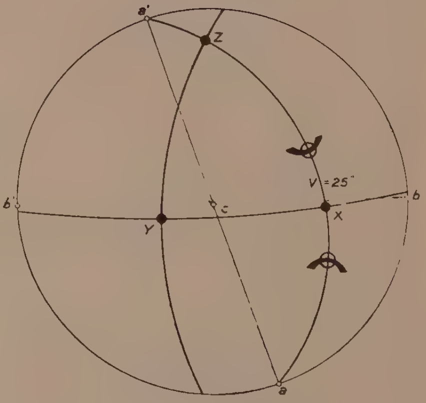
4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V = 25°
b'
c
Y
X
b
a

5

tion of either [*cf*] or [*cM*] is indicated; they proved by calculation to give essentially equal periods. The choice leaned toward the more pronounced zone contained in [*cf*]; this choice was found to lead to simpler indices and was therefore taken as [100].

Figure 1 is the gnomonic projection of the accepted forms of tarbuttite on a plane normal to the chosen vertical axis. The gnomonic plane is also considered as the first layer $|hk1|$ of the reciprocal lattice. The vertical planes ($hk0$) are represented by radial lines drawn from $c\{001\}$ to ($hk1$), the point ($hk1$) being inserted as a large blank circle, *m b k M v*, when it does not represent a known terminal form. These radial lines are thus normal to their respective vertical planes, and their lengths are inversely proportional to the spacings and reticular densities of the corresponding planes in the direct lattice.[1]

The points marked by large filled circles, *c f Z s t W l r h u i*, are nodes of the reciprocal lattice in the first layer and their spacings define the lattice translations. These face poles may be considered as actually in the plane of the gnomonic projection. The small blank circles, *G P F B N H p n q o E*, represent terminal planes which lie on higher lattice layers (hkn) and occupy fractional positions on the gnomonic projection. The representative lattice cell, therefore, may be defined as that cell whose respective reciprocal lattice points, either present or implied, are the three non-colinear points nearest the origin. The point nearest the center *c* represents the axial plane (001); the first layer point nearest *c*, namely *b*, is taken as (011); the next nearest not in zone [*cb*], namely *f*, as (101).

Figure 2 is a typical crystal of tarbuttite in normal position. Figure 2*a* is a crystal of tarbuttite after Spencer, redrawn in normal position.

The most prominent forms in the vertical zone are $a\{100\}$ and $b\{010\}$. The terminal planes are unusually well developed and give remarkably perfect signals. The largest and most frequently observed forms are $c\{001\}$, $G\{1.6.23\}$, $s\{121\}$, $Z\{1\bar{2}1\}$, $W\{\bar{1}11\}$, $l\{\bar{1}21\}$, $E\{\bar{3}\bar{4}7\}$, $u\{\bar{1}\bar{1}1\}$.

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[1] The obliquity of the base is so small that the large blank circles, which would normally appear on the reciprocal lattice projection of the zero layer-line slightly offset from the net intersections, are placed on these intersections to avoid confusion.

Fig. 1. Tarbuttite: gnomonic projection of the accepted forms.

Fig. 2. Tarbuttite: typical doubly terminated crystal from Broken Hill, Northern Rhodesia.

Fig. 2a. Tarbuttite: crystal drawing in new position after Spencer.

Fig. 3. Tarbuttite: relation of Spencer's setting to that of the new position.

Fig. 4. Tarbuttite: stereographic projection of the accepted forms.

Fig. 5. Tarbuttite: stereographic projection of the optical orientation and the position of the optic axes.

These appeared on nearly every crystal measured. The new form $q\{\bar{1}02\}$ was observed on three crystals as a small face in good position.

The singular development of the forms $G\{1.6.23\}$ and $E\{\bar{3}\bar{4}7\}$ is a unique feature of these crystals. On the eleven crystals employed for calculation, *G* was observed eight times and *E* ten times. Their positions in the projection are good and their measured values agree well with these calculated. Added evidence of their rationality is obtained by zonal calculation. The face pole *G* lies at the intersection of two zones $[1\bar{4}1]$ defined by the face poles $\{\bar{1}01\}$ and $\{212\}$, and $[\bar{6}10]$ defined by $\{001\}$ and $\{163\}$; the indices of this zone intersection are $\{1.6.23\}$ which is the symbol determined for *G*. Similarly, *E* lies at the intersection of the zone $[4\bar{3}0]$ passing through the face poles $\{001\}$, $\{\bar{3}\bar{4}3\}$, and the zone $[111]$ containing $\{101\}$, $\{1\bar{2}1\}$; the symbol of the intersection is $\{\bar{3}\bar{4}7\}$, which is the symbol of *E*. The comparatively simple indices of the zones passing through *G* and *E* may be taken as confirming their rational character.

Rosický observed these two forms and gave them the indices $G\{\bar{5}59\}$, $E\{\bar{3}84\}$, which in the new position correspond to $\{0.13.10\}$, $\{\bar{5},\bar{6},11\}$. These are but approximately similar to indices derived from the writer's observations. Comparison of calculated angles for the two sets of symbols (table 1) shows similarity for *E* and an unexplained gross discrepancy for the azimuth angle of *G*.

TABLE 1. TARBUTTITE: COMPARISON OF THE SETS OF INDICES OF *G* AND *E*

	ϕ	ρ
G $\{0.13.10\}$	7°39′	11°00′
$\{1.6.23\}$	20 35	10 47
E $\{\bar{5}.\bar{6}.11\}$	−139 21½	31 58
$\{\bar{3}\bar{4}7\}$	−141 56½	31 42½

Rosický's crystals were of poor quality, which undoubtedly prevented him from determining the true indices of these two forms. Due to the remarkable perfection of development of these forms on the crystals studied here and the excellence of their position on the gnomonic projection, it was decided to adopt new indices while retaining the old letters.

Table 2 gives the measured maximum range, the best measured mean, the calculated ϕ and ρ of the forms, together with the number of times each form was observed. The perfection of the crystals studied is well brought out by the close agreement of the mean measured and the calculated values of ϕ and ρ.

TABLE 2. TARBUTTITE: COMPARISON OF THE MEASURED AND CALCULATED ϕ AND ρ.

Form		Faces	Measured Range		Best Measured Mean		Calculated	
			ϕ	ρ	ϕ	ρ	ϕ	ρ
c	001	11	90°40′– 82°30′	1°47′– 1°30′	87°17′	1°38′	87°00′	1°28½′
b	010	22	359 45 – 0 02	90°00′	0 00½	90 00	0 00	90 00
a	100	20	72 28 – 72 15	90 00	72 19	90 00	72 19	90 00
m	110	4	46 00 – 43 39	90 00	45 15	90 00	45 35½	90 00
k	$2\bar{1}0$	17	91 10 – 90 33	90 00	90 45	90 00	90 39½	90 00
M	$1\bar{1}0$	19	109 15 – 108 47	90 00	109 04	90 00	108 52	90 00
v	$2\bar{3}0$	1	123 56	90 00	123 56	90 00	123 54½	90 00
f	101	11	72 41 – 72 06	42 56 –45 20	72 25	45 34	72 41	45 35
n	$\bar{1}03$	10	−108 17 – 107 52	17 18 –16 50	−108 00	16 57	−108 54	17 04
**q*	$\bar{1}02$	3	−108 19 ––107 37	25 12 –24 57	−108 11	25 03	−108 28½	25 18½
h	$\bar{1}01$	11	−107 51 ––107 38	44 11 –43 53	−107 49	44 07	−108 04	44 09
i	$\bar{3}01$	9	−108 18 ––107 08	71 38 –71 18	−107 44	71 21	−107 37	71 19½
G	1.6.23	8	20 58 – 20 15	11 08 –10 57	20 30	11 00	20 35	10 47½
s	121	5	32 01 – 31 14	61 55 –61 26	31 59	61 34	32 02	61 26
P	$1\bar{2}5$	7	130 39 – 129 50	15 57 –15 06	130 35	15 50	131 14½	15 59½
F	$1\bar{2}3$	10	132 51 – 132 03	25 04 –24 34	132 40	24 52	132 42½	24 57½
Z	$1\bar{2}1$	11	134 29 – 134 07	53 44– 53 23	134 13	53 40	134 15½	53 41
N	$\bar{1}12$	7	− 69 18 –– 68 40	25 47 –25 13	− 69 15	25 34	− 69 58½	25 31½
W	$\bar{1}11$	10	− 70 46 –– 69 47	44 41 –44 25	− 70 35	44 26	− 70 41	44 21½
l	$\bar{1}21$	6	− 44 36 –– 43 37	53 25 –53 00	− 44 11	53 02	− 44 06	52 59
r	$\bar{3}11$	1	−95 36	70 30	− 95 36	70 30	− 95 39½	70 34
E	$\bar{3}\bar{4}7$	10	−141 45 ––141 35	31 40 –31 30	−141 33	31 37	−141 56½	31 42½

* New form.

Correlation of Setting

The relation of Spencer's setting to the writer's is shown in figure 3. From the figure, the form-to-form transformation formula can be directly derived when it is recognized that Spencer's *c* is one-half Richmond's *b*, so that [010] must be multiplied by 2.

Spencer	*Richmond*
a′ $\bar{1}00(100)$	$1\bar{2}1(\bar{1}2\bar{1})$
b 010	$\bar{1}11$
c 001	020

The transformation formula is, therefore, $\overline{11}0/212/\bar{1}10$.

Table 3 shows the forms of tarbuttite observed by Spencer, Rosický and Richmond. The forms represented by a letter in the column *Richmond* are the forms observed by him and accepted as established. Certain additional forms observed by Spencer or Rosický but not by

Table 3. Tarbuttite: Correlation of Form Letters

Form	*Richmond*	*Spencer-Rosický*			*Form*	*Richmond*	*Spencer-Rosický*		
001	*c*	*g*	$\bar{2}21$	*g*	141	*t*†	*t*	$\bar{1}03$	*t*
010	*b*	*c*	001	*c*	412	*B*†	—	$\bar{3}14$	*B*
100	*a*	*d*	$\bar{2}\bar{2}3$	*d*	$1\bar{2}5$	*P*	—	$\bar{3}21$	*P*
110	*m*	—	$\bar{2}\bar{2}5$	*y*	$1\bar{2}3$	*F*	—	$\bar{4}21$	*F*
430	?	—	$\bar{4}\bar{4}9$	*L*	$5\bar{4}3$	?	—	$\bar{8}25$	*M*
210	?	—	$\bar{1}\bar{1}2$	*x*	$1\bar{2}1$	*Z*	*a*	100	*a*
$2\bar{1}0$	*k*	*k*	$\bar{1}\bar{1}1$	*k*	$\bar{9}.10.15$	?	—	$\bar{3}.12.2$	*w*
$1\bar{1}0$	*M*	*e*	$\bar{2}\bar{2}1$	*e*	$\bar{1}12$	*N*	—	$\bar{2}61$	*N*
$10.\overline{11}.0$	?	—	$\bar{5}\bar{5}2$	*z*	$\bar{8}.13.10$	*H*†	—	$\bar{1}93$	*H*
$2\bar{3}0$	*v*	*m*	110	—	$\bar{1}11$	*W*	*b*	010	*b*
$0\bar{7}4$	?	—	$\bar{4}45$	*C*	$\bar{5}95$	*p*†	—	052	*p*
$0\bar{3}1$	?	—	—	—	$\bar{1}21$	*l*	*l*	021	*l*
$0.\overline{11}.2$	?	—	$1\bar{1}5$	*D*	$\bar{3}11$	*r*	*r*	$\bar{2}\bar{4}3$	*r*
101	*f*	*f*	$\bar{1}01$	*f*	$\bar{3}21$	?	—	—	—
$\bar{1}03$	*n*	—	$\bar{2}01$	*n*	$\bar{1}23$	*o*†	*O*	$1\bar{2}1$	—
$\bar{1}02$	*q**	—	—	—	$5.\bar{6}.11$	?	—	384	*E*
$\bar{1}01$	*h*	*h*	$0\bar{2}1$	*h*	$\bar{3}\bar{4}7$	*E*	—	—	—
$\bar{3}01$	*i*	*i*	$\bar{1}22$	*i*	$\bar{1}\bar{1}1$	*u*†	*u*	$0\bar{1}1$	—
1.6.23	*G*	—	—	—					
0.13.10	?	—	$\bar{5}59$	*G*					
121	*s*	*s*	$\bar{1}02$	*s*					

* New form.

TABLE 4. TARBUTTITE: $Zn_2PO_4(OH)$

Triclinic; pinacoidal-$\bar{1}$

$a:b:c=0.6296:1:0.5971$; $\alpha=89°37\frac{1}{2}'$, $\beta=91°28\frac{1}{2}'$, $\gamma=107°41'$

$p_0:q_0:r_0=0.9954:0.6265:1$; $\lambda=89°55\frac{1}{2}'$, $\mu=88°34\frac{1}{2}'$, $\nu=72°19'$

$p_0'=0.9957$, $q_0'=0.6267$; $x_0'=0.0258$, $y_0'=0.0014$

	Form	φ	ρ	A	B	C
c	001	87°00′	1°28½′	88°34½′	89°55½′	—
b	010	0 00	90 00	72 19	—	89°55½′
a	100	72 19	90 00	—	72 19	88 34½
m	110	45 35½	90 00	26 43½	45 35½	88 53½
k	$2\bar{1}0$	90 39½	90 00	18 20½	90 39½	88 31½
M	$1\bar{1}0$	108 52	90 00	36 33	108 52	88 37½
v	$2\bar{3}0$	123 54½	90 00	51 35½	123 54½	88 49
f	101	72 41	45 35	44 25	77 43½	44 16
n	$\bar{1}03$	−108 54	17 04	107 04	95 27½	18 29½
**q*	$\bar{1}02$	−108 28½	25 18½	115 18½	97 47	26 44
h	$\bar{1}01$	−108 04	44 09	134 09	102 28½	45 34½
i	$\bar{3}01$	−107 37	71 19½	161 19½	106 40	72 45½
G	1.6.23	20 35	10 47½	83 20½	79 54½	10 17
s	121	32 02	61 27	47 56	41 53	60 35½
t	141	19 07½	71 25	55 24	26 25	70 52
B	412	64 26½	64 52	26 15½	67 00½	63 30½
P	$1\bar{2}5$	131 14½	15 59½	81 49½	100 49½	14 57½
F	$1\bar{2}3$	132 42½	24 57½	77 58	106 37½	23 56½
Z	$1\bar{2}1$	134 15½	53 41	67 44	124 13	52 41½
N	$\bar{1}12$	− 69 58½	25 31½	109 56	81 31	26 53
H	8.13.10	− 51 56½	42 57½	112 33½	65 09½	44 05
W	$\bar{1}11$	− 70 41	44 21½	124 27	76 37½	45 44
p	$\bar{5}95$	− 48 08½	51 06	126 18½	58 43	51 56
l	$\bar{1}21$	− 44 06	52 59	110 48½	55 01½	53 57½
r	$\bar{3}11$	− 95 39½	70 34	157 16	95 20	72 02½
o	$\bar{1}\bar{2}3$	−150 41	30 40½	111 54½	116 25	30 42½
E	$\bar{3}\bar{4}7$	−141 56½	31 42½	115 44½	114 26½	32 42
u	$\bar{1}\bar{1}1$	−135 09	52 37	134 49	124 17	53 43½

* New form.

Richmond are indicated by a dagger after the letter. Forms not observed by Spencer or Rosický are followed by a dash. Forms represented by a ? in column *Richmond* were discredited by him for one or more of the following reasons: (1) observed but once and in poor position, (2) calculated values not in agreement with actual measurements, (3) complexity of symbols and poor position.

Using the method outlined by Wolfe (1937), we transform Spencer's elements to those in the writer's setting and obtain: $a:b:c=0.6332:1:0.6047$; $\alpha=89°14\frac{1}{2}'$, $\beta=92°26\frac{1}{2}'$, $\gamma=108°00'$.

The elements from the new measurements are: $a:b:c=0.6296:1:0.5971$; $\alpha=89°37\frac{1}{2}'$, $\beta=91°28\frac{1}{2}'$, $\gamma=107°41'$.

The two sets of elements are not in close agreement. Spencer states that his elements are only "a first approximation," being derived from crystals unsuitable for accurate measurements. The crystals here studied are of such exceptional quality that measured and calculated values agree closely. The new elements are therefore adopted and employed to derive the formal angle table for the accepted forms of tarbuttite in the new setting (table 4).

Figure 4 is a stereographic projection of the accepted forms of tarbuttite.

OPTICS

The optical properties of tarbuttite were determined on a small crystal mounted on the universal stage, and by the immersion of crystal fragments. The optical data are summarized in table 5.

TABLE 5. TARBUTTITE: OPTICAL DATA

	ϕ	ρ	n(Na)		
X	7°	58°	1.660	±0.003	negative
Y	159	25	1.705		2V=50°
Z	−86	80	1.713		no pleochroism

The optical orientation and the positions of the optic axes in relation to the principal planes of the crystal are represented stereographically in figure 5.

PSEUDOSYMMETRY

The new setting of tarbuttite brings out certain pseudosymmetrical elements which are graphically illustrated in figures 1 and 6. In figure 1 the dotted lines outline one pseudoisometric cell. The direction of the unit prism *m* is approximately in the 45° position and *k* at 90°; *c* is close to the center of the projection. Figure 6 is a clinographic drawing of the direct lattice cell of tarbuttite (small) and shows the relation of the unit cell to that of the pseudoisometric (heavy dashes).

STRUCTURAL LATTICE

X-ray measurements were made on a single carefully selected crystal 0.5 millimeter in the longest direction. The six lattice elements were determined by rotation and Weissenberg photographs of the zero and first layer-lines rotating the crystal successively about the three chosen crystallographic axes.

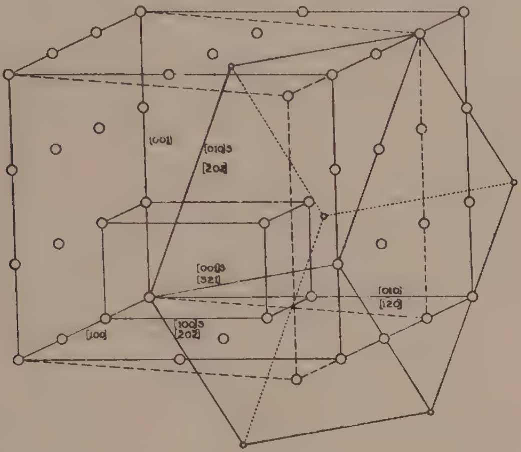

FIG. 6. Tarbuttite: relation of the several direct lattice cells.

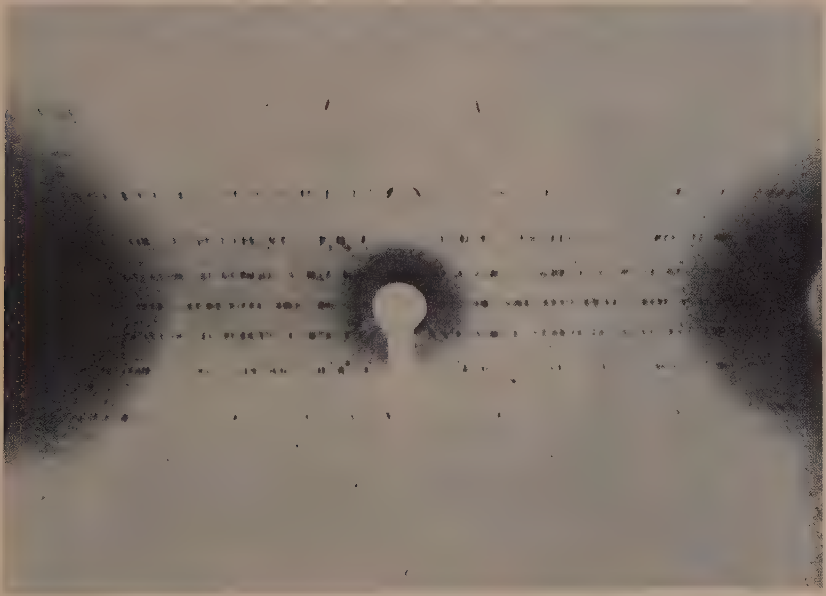

FIG. 7. Tarbuttite: rotation photograph about the c-axis; unfiltered copper radiation.

Excellent photographs were obtained with copper radiation. The films were practically unfogged by scattered radiation due to the shortness of the exposure time. The diffraction spots were exceptionally sharp so that it was possible to measure and calculate the lattice elements with considerable accuracy.

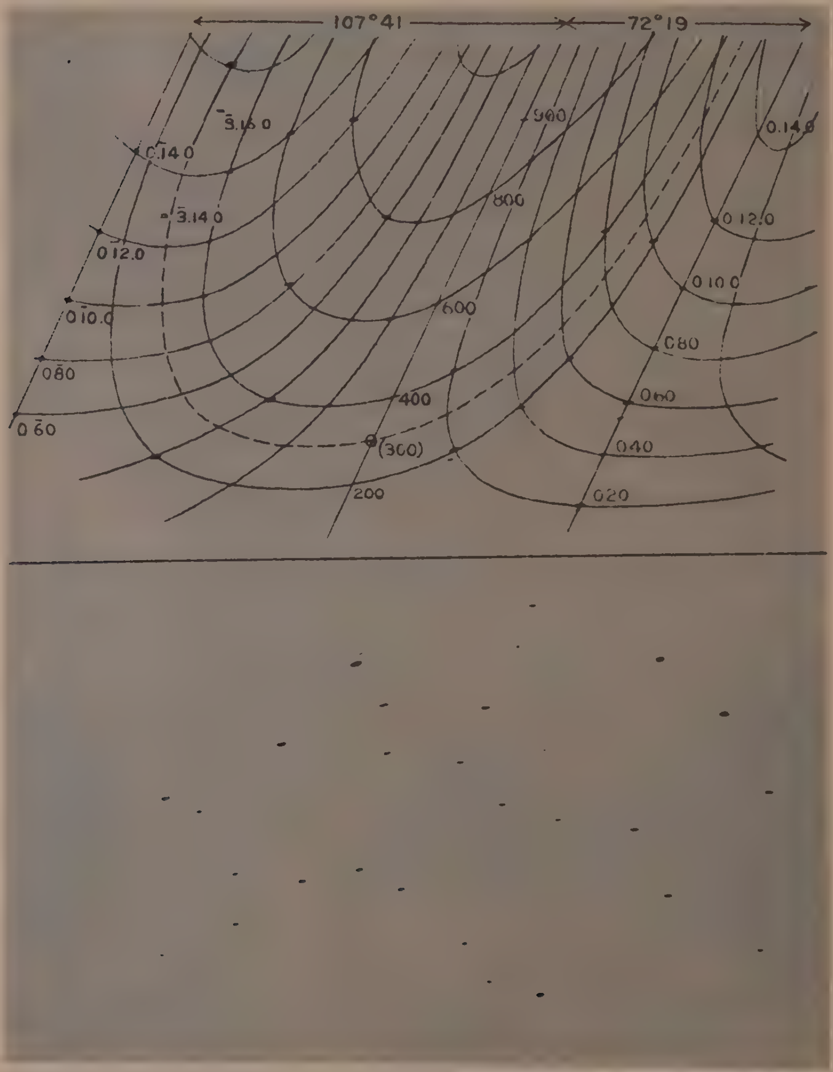

FIG. 8. Tarbuttite: zero layer-line photograph about *c*-axis; unfiltered copper radiation.

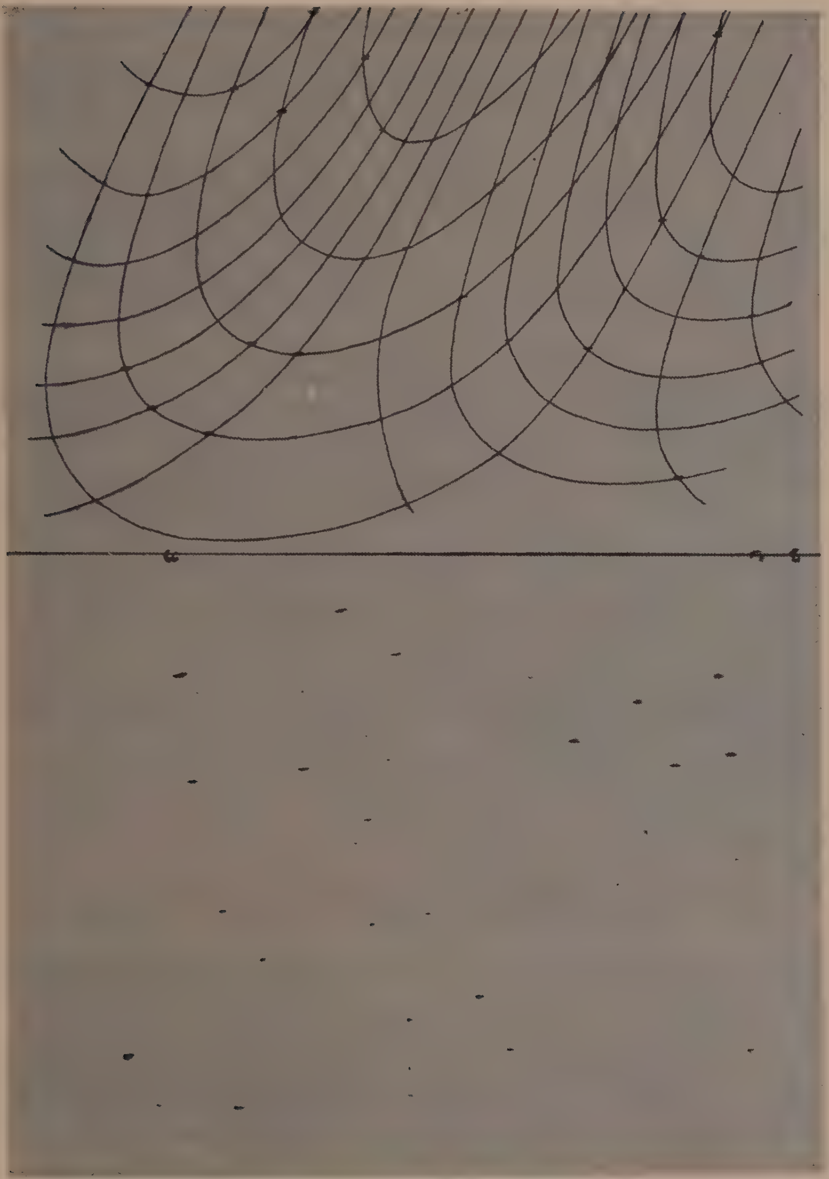

FIG. 9. Tarbuttite: first layer-line photograph about c-axis; copper radiation; nickel filter.

The exceptional quality of the photographs is shown in figures 7, 8, and 9. The rotation and zero layer-lines were taken without a filter (figures 7, 8), while a nickel filter was used for the first layer-line (figure 9). The zone lines have been drawn in on the zero and first layer line photographs and the intersection of the zone lines with the axial directions indexed. These photographs were all taken about the *c*-axis.

The zero layer-line photographs taken about the three zone axes gave three pairs of values for the spacings of the axial planes. The reciprocal axial angles were determined by lattice spacing measurements along lattice cell diagonals and by triangulation calculations. The lattice constants measured and computed are shown in table 6.

TABLE 6. TARBUTTITE: STRUCTURAL LATTICE CONSTANTS

From rotation photographs	From Weissenberg photographs			
Å			Å	
$a_0 = 8.062$	$d_{100} = 7.706$	$\alpha^* = 89°51'$	$a_0 = 8.097$	$\alpha = 89°34\frac{1}{2}'$
$b_0 = 12.86$	$d_{010} = 12.29$	$\beta^* = 88\ 27$	$b_0 = 12.91$	$\beta = 91\ 35\frac{1}{2}$
$c_0 = 7.687$	$d_{001} = 7.685$	$\gamma^* = 72\ 14$	$c_0 = 7.688$	$\gamma = 107\ 47$

A study of the lattice parameters shows that the three chosen axes of rotation, which were previously taken as the three crystallographic axes, are also the three shortest noncoplanar lattice periods.

The direct lattice elements calculated from the Weissenberg photographs give the following ratio, which agrees well with that computed from the geometrical elements.

$$a_0 : b_0 : c_0 = 0.6271 : 1 : 0.5957; \quad \alpha = 89°34\tfrac{1}{2}', \quad \beta = 91°37\tfrac{1}{2}', \quad \gamma = 107°47'$$
$$a : b : c = 0.6296 : 1 : 0.5971; \quad \alpha = 89°37\tfrac{1}{2}', \quad \beta = 91°28\tfrac{1}{2}', \quad \gamma = 107°41'$$

The relation of Spencer's lattice cell (large cell with solid and dotted lines) to that in the new position is shown in figure 6.

The method outlined by Wolfe and used to transform Spencer's elements to those in the new position may also be employed to calculate the edge lengths of the Spencer cell in the new position as well as the volume of that cell. This method makes use of the transformation formula Spencer to Richmond ($\bar{1}\bar{1}0/212/\bar{1}10$) and the absolute lengths of the chosen unit cell. Matrix calculation of the Spencer to Richmond transformation together with translation formulae give the following relationship:

$$\begin{array}{llll}
a' & [100]=[\bar{2}0\bar{2}]=22.03\text{Å} & \qquad a_0= & 8.097\text{Å} \\
b' & [010]=[\bar{2}02]=22.58 & \qquad b_0= & 12.91 \\
c' & [001]=[321]=30.46 & \qquad c_0= & 7.69
\end{array}$$

$$\begin{array}{ll}
\alpha' & [010]\wedge[001]=[\bar{2}02]\wedge[321]=100°06\tfrac{1}{2}' \\
\beta' & [001]\wedge[100]=[321]\wedge[\bar{2}0\bar{2}]=123\ 54\tfrac{1}{2} \\
\gamma' & [100]\wedge[010]=[\bar{2}0\bar{2}]\wedge[\bar{2}02]=\ 89\ 42
\end{array}$$

From the volumetric formula the volume of the Spencer cell is 12,297.45 cu. Å. The volume of the new unit cell is 765; therefore the volume of Spencer's cell is 16.06 cu. Å (ca. 16.00) times that of the unit cell, which is also a reflection of the accuracy of the preceding calculations.

CONTENTS OF THE UNIT CELL

The chemical analysis of tarbuttite by Spencer gives the formula $Zn_2PO_4(OH)$. The determined elements of the structural lattice give the volume of the unit cell, $V_0=764.9$, which, with the given density 4.15, makes the cell molecular weight, $M_0=1924$. The analysis then gives the number of molecules in the unit cell as shown in table 7.

TABLE 7. TARBUTTITE: MOLECULAR CONTENT OF THE UNIT CELL

	1	2	3	4
ZnO	66.6	0.822	15.81	16
P_2O_5	29.2	0.205	3.94	4
H_2O	3.8	0.212	4.08	4

1. Tarbuttite, Broken Hill mines, N.W. Rhodesia; Spencer, *analyst.*
2. Molecular proportions from analysis reduced to 100%.
3. Number of molecules in the unit cell.
4. Number of molecules in the unit cell reduced to the nearest whole number.

The molecular content of the unit cell is, therefore, 16ZnO, $4P_2O_5$, $4H_2O$, giving the cell formula $8[Zn_2PO_4(OH)]$.

ACKNOWLEDGMENTS

This work was undertaken during the investigation of minerals of the chemical type $R_2XO_4(Z)$ under the direction of Professor Charles Palache, whose critical observations have aided materially in its preparation. I also wish to thank Drs. M. A. Peacock and Harry Berman for many helpful suggestions.

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NOTES AND NEWS

CADMIUM IN SMITHSONITE FROM NEW MEXICO*

W. T. Schaller and J. G. Fairchild,
U. S. Geological Survey, Washington, D. C.

Two specimens of yellow smithsonite from the Kelly mine, Magdalena district, Socorro County, New Mexico, presented to G. F. Loughlin by the late C. T. Brown of Socorro, N. M., were studied to determine the quantity and distribution of any cadmium present.

A polished surface on one of the reniform banded specimens (Fig. 1, natural size) shows the variously colored, slightly wavy, concentric layers, each from 2 to 4 millimeters wide, surrounding a central, somewhat cavernous mixture, about 5 to 9 millimeters thick, of dominantly brown iron oxide with green malachite and white smithsonite.

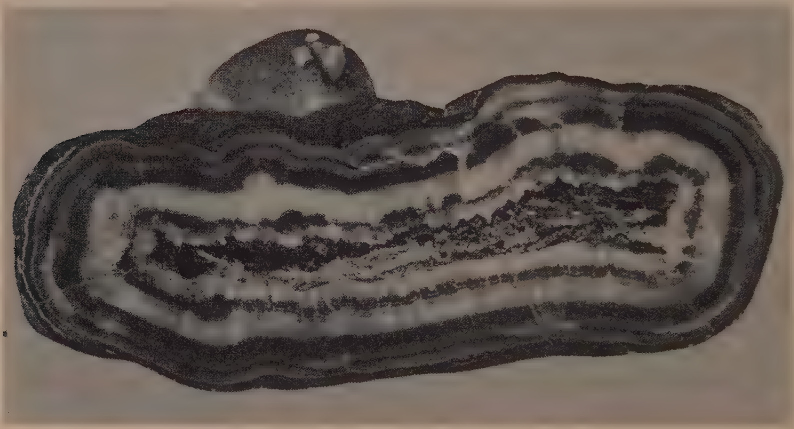

Fig. 1. Reniform, banded smithsonite from the Kelly mine, Magdalena district, Socorro County, New Mexico. Natural size.

Layer 1 is brownish amethystine, layer 2 is milky white, layer 3 is yellow (black in the reproduction), and layer 4 is white or nearly colorless, with fine bands of brown iron oxide.

From the center outward, these layers are as follows:

First layer (analysis no. 1, brownish amethystine), about 4 millimeters wide, has a narrow non-continuous white zone adjacent to the central iron oxide, but most of it is of a brownish amethystine color, with narrow brownish bands of manganese oxide (?). This first layer grades imperceptibly into the second milky white layer.

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* Published by permission of the Director, U. S. Geological Survey.

Second layer (analysis no. 2, milky white), about 2 millimeters wide, contains a few very thin bands of the first layer. In the reproduction (Fig. 1), this second layer appears wider than it really is as part of the first layer photographed the same color.

Third layer (analysis no. 3, yellow) about 4 millimeters wide, has a sharp contact with the second or milky white layer and, although yellow throughout, shows varying intensities of yellow in different places, better seen in thin section than on the polished specimen.

Fourth and outside layer (not analyzed) 2 to 4 millimeters wide, is white or nearly colorless with several thin brown bands of iron oxide.

A thin section across the variously colored layers shows no difference between them except that in the yellow area the stronger color is present in irregular blotches suggesting that cadmium sulphide is disseminated through the smithsonite in an extremely fine state of division. The different colors seen on the hand specimen are probably due to a very slight variation in the quantities of the chromatic compounds, which probably have a compensating effect in the white smithsonite.

Partial Analyses of Variously Colored Layers of Smithsonite from the Kelly Mine, Magdalena District, Socorro County, New Mexico

	First specimen			Second specimen	
	1 Brownish amethystine	2 Milky white	3 Yellow	4 Milky white	5 Yellow
Cadmium (Cd)	.40	.44	.56	.39	.57
Manganese oxide (MnO)	.57	.56	.34	.58	.34
Ferrous oxide (FeO)	1.46	1.03	1.31	(*a*)	1.56
Lead oxide (PbO)	(*b*)	.33	Trace	(*b*)	Trace
Insoluble in HCl	.04	.01	.01	.01	.02

(*a*) Present but not determined.

(*b*) Present, more than a trace, but not determined.

Cadmium in no. 1 determined by Schaller; in no. 2 the average of 0.45 (Fairchild) and of 0.45 and 0.39 (Schaller); in no. 3 the average of 0.58 (Fairchild) and of 0.58 and 0.51 (Schaller); in no. 4 determined by Schaller; in no. 5 the average of 0.56 (Fairchild) and 0.58 (Schaller).

Ferrous oxide (total iron) and insoluble determined by Schaller, lead oxide by Fairchild, and manganese oxide by George Steiger.

Parts of both specimens were crushed and the fragments hand-sorted, on the basis of color, into brownish-amethystine, milky white, and yellow fractions from one specimen, and into milky white and yellow from the second specimen. The amethystine layer is present on the second specimen but fragments from this layer could not well be isolated. The fractions were partially analyzed with the above results. The milky white layers from the two specimens and the yellow layers from the two specimens gave very similar results.

Expressing the total content of cadmium as $CdCO_3$, the equivalents will be, on the average, 0.87 per cent for the yellow smithsonite and 0.63 per cent for the amethystine and white smithsonite.

The yellow layer (no. 3) contains more cadmium and less manganese and lead than the amethystine and white layers. The content of iron shows no regular variation.

Spectrographic tests for Ag, As, Be, Bi, Ga, Ge, In, Re, Sb, Sn, and Tl, made by George Steiger, gave no evidence of their presence in any of the five samples tested.

Qualitative tests for sulphide, as H_2S, evolved by treatment with hydrochloric acid and testing with moist lead acetate paper, which turns black if H_2S is present, gave the following results.

PRESENCE OF SULPHIDE

1	2	3	4	5
Brownish amethystine	Milky white	Yellow	Milky white	Yellow
Trace	Trace	Strong	Weak	Strong

As the two samples of yellow smithsonite (nos. 3 and 5) give a strong test for H_2S, it would seem that the cadmium is present as sulphide. But as samples nos. 1, 2, and 4, which are not yellow and give only a faint test for H_2S, nevertheless contain, on an average as much as 72 per cent of the cadmium content of the yellow smithsonite, it would seem that most of the cadmium in these differently colored varieties of smithsonite is present as carbonate and that only a minor quantity is present in the yellow smithsonite as sulphide.

That cadmium is present in two forms in yellow smithsonite is also suggested by the analysis of a bright yellow variety from Marion County, Arkansas. H. N. Stokes reports[1] in his analysis 0.63 per cent of CdO and 0.25 per cent of CdS, confirming the conclusion reached as a result of the determinations on the smithsonites from the Kelly mine, namely, that most of the cadmium present in yellow smithsonite is there as the carbonate. It also follows that the lack of a yellow color in any smithsonite is no indication of the absence of cadmium.

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[1] Dana, E. S., *System of Mineralogy*, 6th ed., p. 279, 1892.

The quantities of cadmium in the brownish amethystine and milky white varieties are unexpectedly high. They suggest that cadmium may be more generally present in smithsonites than has been commonly realized. Apparently the presence of only a few tenths of a per cent of yellow cadmium sulphide is sufficient to color smithsonite yellow.

The special method used here for determining Cd has been published in the Chemist Analyst (published by J. T. Baker Chemical Co.), vol. **20,** p. 5, May 1931. For easy reference, a brief summary of the necessary procedure will be given.

Precipitation of CdS is made in a 200 ml. Erlenmeyer flask provided with inlet and outlet tubes. Besides zinc, only a small quantity of iron, manganese, and possibly lead, should be present as heavy metals. The first precipitation is made with H_2S in an acidity of cold 0.3N H_2SO_4, and carries much ZnS. Filter after 1 hour, wash once with cold water and dissolve the precipitate in 1:1 HCl. Evaporate to dryness and dissolve the residue in 50 ml. 0.3N H_2SO_4. Repeat the precipitation with H_2S twice. The third precipitation may be made in 0.6N H_2SO_4 with a liberal excess of H_2S.

If the second precipitate is dark colored, lead is probably present and should be separated as $PbSO_4$ before the final precipitation of CdS. Cadmium is then weighed as $CdSO_4$ by converting CdS to $CdCl_2$ which in turn is evaporated and ignited in a platinum crucible with a drop of 1:1 H_2SO_4.

NOTES ON MINERALS ASSOCIATED WITH HILGARDITE

Cornelius S. Hurlbut, Jr., *Harvard University*, and
Ralph E. Taylor, *Louisiana State University*.[1]

A general discussion of the water-insoluble residues from the rock salt of Louisiana salt plugs has been given by Taylor (1937). A new mineral, hilgardite, described by Hurlbut and Taylor (1937), and an associated mineral, parahilgardite, described by Hurlbut (1938), were found in the Choctaw salt dome. In addition to these minerals, the insoluble residues from the Choctaw salt dome yielded several others worthy of note because of their unusual occurrence and association.

The insoluble residue which separates from the brine comes from well within the salt dome and is composed largely of anhydrite grains mixed with fragments of argillaceous sandstone and black calcareous shale. The other minerals form but a small percentage of the total residue. The minerals identified from the residue are briefly described below in order of abundance.

Anhydrite. A bluish gray color is given to the residue by the large percentage of anhydrite present. It is found chiefly as cleavage fragments somewhat etched and worn by solution, some of which include carbonaceous matter. Occasional partially developed tabular crystals are found elongated parallel to either the *a*[100] or *c*[010] axis. The grains average from 0.1 to 0.8 mm. in length, with an occasional one as long as 15 mm.

Dolomite. Crystals of dolomite, unusually well developed, make up nearly five per cent of the total residue. Cleavage fragments and irregular grains are present but are much less common than the crystals. The base {0001} dominates the crystals, but its modification by the positive rhombohedron $\{10\bar{1}1\}$ and the negative rhombohedron $\{01\bar{1}2\}$ gives the crystals a star-shaped appearance as shown in Fig. 1. When transparent, or nearly so, the crystals show definite nuclei of a finely divided white substance. Such crystals are slowly soluble in cold 1:1 HCl, leaving the finely divided white substance of the nucleus as a residue.

On the basis of refractive indices some of the dolomite can be separated into the varieties magnesiodolomite and ankerite. The ankerite differs from the magnesiodolomite in containing a higher percentage of iron, which gives it a yellow to orange color and higher refractive indices.

Magnesite. One of the interesting features of the residue is the presence of well-developed magnesite crystals, for crystals of this mineral have been described from only a few places in the world. The crystals are clear and colorless and range from 0.1 to 3.0 mm. in length. The second order prism $a\{11\bar{2}0\}$ is the dominant form and is frequently the only one, for many of the terminations are either deeply etched or broken. A few crystals show a positive rhombohedron, probably $r\{10\bar{1}1\}$, and the base, $c\{0001\}$, but too deeply etched to permit measurement. The cleavage angle $rr'(1011):(\bar{1}101)=72°36'$ and $cr(0001):(10\bar{1}1)=43°8'$ check exactly the angles of Kokshorov given by Dana (1892). The refractive indices determined with sodium light are: $\omega=1.701\pm0.002$ and $\epsilon=1.508\pm0.003$, which check within the limits of error the refractive indices given by Larsen and Berman (1933) for pure $MgCO_3$.

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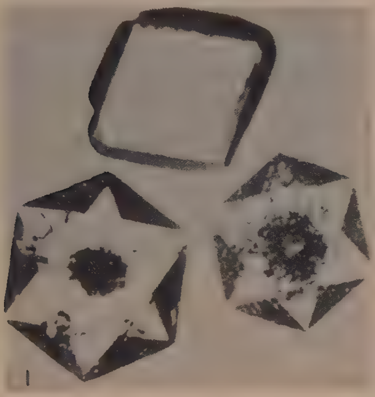
[1] Now with Freeport Sulphur Co., Port Sulphur, La.



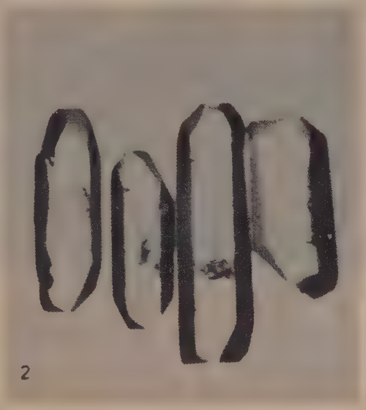


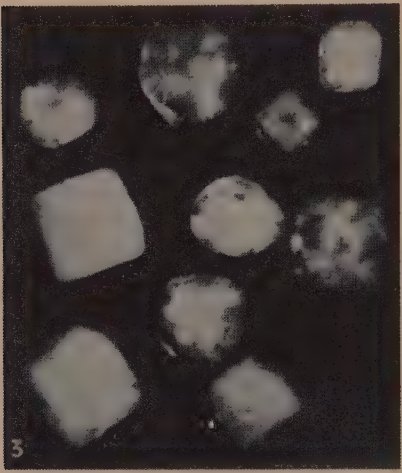
FIG. 1. Dolomite crystals showing nuclei. ×21.
FIG. 2. Magnesite crystals, ×25.

Hilgardite and Parahilgardite. The new hydrous calcium borates, hilgardite and parahilgardite, have been described by Hurlbut and Taylor (1937) and Hurlbut (1938).

Pyrite. Well-developed pyrite crystals occur in a variety of forms. Pyrite is also found as irregular grains, as inclusions in anhydrite and dolomite, and as crusts on grains of other minerals.

Calcite. For the most part calcite is represented by irregular grains and cleavage fragments with an occasional crystal. The crystals are more elongated and less well developed than those of dolomite, and show faces of a positive scalenohedron, negative rhombohedron, and prism. A few nearly perfect scalenohedrons are also present. All of the calcite grains and crystals are less than 1.0 mm. in greatest dimension.

Boracite. While boracite is found in many of the German salt deposits, its appearance at Choctaw is believed to be the first described for an American locality. The crystals range from 0.1 to 0.5 mm. in diameter and have the form of cubes truncated by the octahedron. They have the characteristic twinning producing an internal radial structure and pearly luster. Photomicrographs of boracite crystals are shown in Fig. 3.



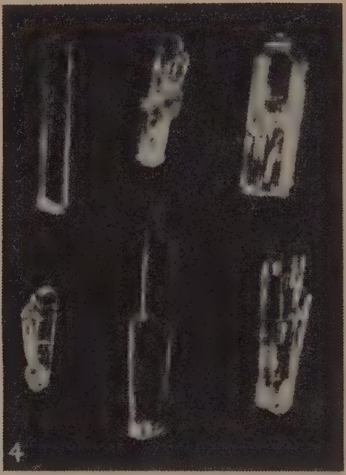


FIG. 3. Boracite crystals, ×23.
FIG. 4. Danburite crystals, ×14.

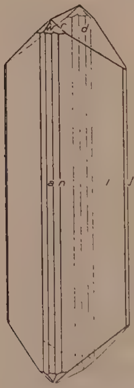


FIG. 5. Doubly terminated crystal of Danburite.

Danburite. One of the most interesting of the minerals present in the residue, because of its unusual occurrence, is danburite. So far as is known, this is the first time danburite has been found in such an association. It occurs as colorless prisms as much as 3.0 mm. in length, and characteristically intergrown in a subparallel manner. Isolated individuals are doubly terminated as shown in Fig. 5. Photomicrographs of typical crystals are shown in Fig. 4. The following forms were found on the crystals: $a\{100\}$, $h\{210\}$, $l\{110\}$, $j\{120\}$, $d\{011\}$, $w\{201\}$, $r\{111\}$.

Quartz. Sandstone inclusions occur in the residue, but, in addition to these, there are quartz crystals that have developed independently. The crystals are clear or with inclusions of carbonaceous matter, and have the usual prisms terminated by rhombohedrons. They occur as individuals, or in the form of rosettes with nuclei similar to those in the dolomite crystals. The largest rosettes are not greater than 1.0 mm. in diameter.

Sulphur. Yellow to greenish-yellow sulphur grains with diameters up to 0.5 mm. are present; most of them are quite irregular, but a few have partially developed crystal faces.

Limonite. Limonite pseudomorphs after pyrite, rarely larger than 0.1 mm. in diameter, are present.

Hematite. Hexagonal plates and irregular grains of hematite are found, seldom over 0.2 mm. in greatest dimension.

Marcasite. Characteristic coxcomb aggregates of elongated microscopic marcasite crystals are present but rare.

Hauerite. Only a few crystals and irregular grains of hauerite are present. These have a grayish- to reddish-brown color and a maximum dimension of less than 1.0 mm.

Gypsum. Occasional selenite crystals and fibrous masses of gypsum are attached to shale fragments. These have the appearance of being secondary and it seems probable that they are, since the sample had been exposed to the weather before it was collected.

The Zechstein salt deposits of Germany have been studied in much greater detail than those of any other region. Boeke (1910) has summarized the data on the insoluble residues of these deposits, and his list of minerals includes most of those found in the Choctaw salt dome and many that are not. The outstanding feature of the Choctaw residues is the relative abundance of boron minerals—boracite, danburite, hilgardite, and parahilgardite. Boracite is the only one of these boron minerals that has been found in the Zechstein deposits. Taylor (1937), in the study of insoluble residues from twenty Gulf Coast localities found boron minerals in only the Choctaw salt dome. As the salt of the domes has been intruded from sedimentary beds at depth and the minerals of the residues are considered to be syngenetic in the salt, the Choctaw salt dome must represent an area of unusual boron concentration for the Gulf Coast region. A brine sufficiently concentrated for the precipitation of boron minerals might have developed in an isolated basin, or the boron might be of local volcanic origin, as in the case of the Searles Lake, California, deposits.

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MISSISSIPPI MINERALS SURVEY DISCLOSES HIDDEN WEALTH

Enormous deposits of industrially valuable minerals disclosed by a survey in a single Mississippi County have resulted in an awakening of Mississippians to the potential wealth lying beneath their soil. Projected studies of 11 additional counties in the state consequently are attracting wide interest.

The original survey was undertaken in Winston County by the Works Progress Administration, under the sponsorship of the Mississippi Geological Survey, to determine the mineral resources of the area and to make chemical, physical and ceramic tests of the minerals discovered.

Obviously, a complete mineral analysis of the State would be of tremendous importance in any effort to develop industries to process such resources as the State's clays, its limestone, its aluminum ores, pigments and other minerals.

While inhabitants of Winston County, since the days of the Choctaw Indians, have relied largely upon the soil for support, the wealth of minerals lying beneath the soil long has lain neglected; the use of the county's clays and lignite beds has been of the most elementary nature. Neither has the full extent of the deposits ever been determined, nor their commercial value determined. Previous investigations have been in the nature of preliminary studies, but these, while disclosing no spectacular resources in metals or precious stones, have shown enormous deposits of non-metallic minerals.

It was known that the dark "Porters Creek" clay of the Flatwoods in the northeastern corner of the county could be burned to form excellent brick; that the central part of the county contained deposits of clay suitable for brick and pottery, as well as of lignite, bauxite and possibly iron ores; and that there were possible valuable beds of sand and pottery clay in the western section. But little was known as to their actual commercial worth.

When the WPA survey project was launched, Frederic F. Mellen, a young Mississippi geologist who has studied the earth strata of the county, foot by foot, through the successive layers, was put in charge. Under his direction, WPA workers have sunk trenches into the bluffs and dug pits into the plains, from which are taken samples of the various minerals to be found.

Entries have been driven into hillsides to determine the exact undercover thickness of lignite beds, and in more level stretches the workers have bored holes to measure, to the nearest tenth of a foot, the thickness of clay and lignite beds. Sample men have taken clean samples of the mineral deposits, recording their exact geographic and geologic position, as well as information regarding the amount of over-burden, tonnage of the mineral available and the accessibility of the deposit.

Clay samples in 200-pound units from the Winston County survey are being tested at the University of Mississippi where ceramic tests of the clays are being made under a companion WPA project. These tests are directed by T. E. McCutcheon, a ceramic engineer, using equipment purchased in 1929 by the State Geologic Survey.

These samples, after being ground, quartered, screened and wedged, are formed by WPA workers into bars one inch square which then are cut into one-inch, two-inch and six-inch lengths. In the unfired state some of the bars are tested as to their volume and linear percentage of shrinkage on drying, and as to their transverse breaking strength, while others, fired to various temperatures, are tested as to porosity, absorption, specific gravity, volume shrinkage, linear shrinkage and the transverse breaking strength.

These tests determine the firing for color range of the clays if put to ceramic uses. Combined with information concerning the chemical composition of the minerals, the tests supply all the data necessary for industrial use of the clays.

Mr. Mellen is preparing a geologic report of the county, based on the detailed field survey of the county's minerals, while a companion report is also being prepared on the detailed reports of the tests, especially the ceramic tests, being made at the State University, with the probability that both will be published by the State Geological Survey.

Because of federal restrictions, and the limited capacity of the testing equipment at the University laboratory, only three county surveys can operate concurrently. Tippah and Lauderdale are the two chosen for surveys pending the completion of the Winston County studies; other counties from the 12 selected will be studied as the surveys already under way are completed.

The ultimate effect of these surveys upon the industrial development of the State remains to be seen, but it is the hope of Dr. William Clifford Morse, state geologist and director of the State Geological Survey, that they will prove of sufficient value to warrant mineral studies in all the other counties of the State.

Works Progress Administration

BOOK REVIEW

QUARTZ FAMILY MINERALS. A HANDBOOK FOR THE MINERAL COLLECTOR. By H. C. Dake, Frank L. Fleener and Ben Hur Wilson. 304+xvi pages. McGraw-Hill Book Co., Inc. *New York*, **1938.** Price $2.50.

In this book of fifteen chapters the authors present a general discussion of quartz proper, the cryptocrystalline varieties of quartz and opal. The concluding chapter of 19 pages describes the art of cutting quartz. The book is intended primarily for the layman and mineral collector. The large number of illustrations together with a free and easy style of presentation has produced an interesting volume which should prove very popular.

Unfortunately, in numerous instances, the statements are either vague or inaccurate. Frequently the cryptocrystalline varieties are referred to as "amorphous," while the formula for opal (p. 35) is given as "$SiO_2 \cdot H_2O$," in which the water is referred to as "water of crystallization." The reader is informed (p. 85) that "silica crystallizes only below 800°C," and that quartz melts at "1600°C" (p. 36). Also, in discussing the sequence of crystallization of the various minerals from a magma (p. 48), the reader is told that the order of separation is based upon "congealing temperatures." Petrologists are agreed that laws of solubility control the sequence of separation.

While these "oversights" and others are not serious, perhaps, from the standpoint of the mineral collector, they do detract however from the scientific value of the book.

W. F. H.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences, Sept. 1, 1938

A stated meeting of the Philadelphia Mineralogical Society was held on September 1st, 1938, with the president, Mr. Trudell, in the chair. The treasurer, Mr. Flack, reported a balance on hand of $101.88, no money owing, and $210.50 receivable. The present officers were elected unanimously for the coming season.

The subject for the evening was "New Techniques of Modern Mineralogy," by Mr. William Parrish of the Massachusetts Institute of Technology. The first of the techniques described by Mr. Parrish was *x*-ray analysis. The speaker described, with illustrations, the use of the Bragg spectrometer, the powder method, and the Weissenberg method, showing photographic results obtained by each. Mr. Parrish then described the silica tetrahedron and its importance in silicate structures. He emphasized the relation between the structure of the crystals of rock-forming minerals and the petrology of the rocks in which they occur.

Another new technique is that of colorimetric analysis, now being developed by Mr. Parrish and his colleagues. The apparatus used, a recording photo-electric photometric spectrometer, was illustrated, and its use described. The analytical results expected of colorimetric analysis are: reflectivity, absolute color, identity, density, and conductivity. A vote of thanks was tendered Mr. Parrish for his lucid interpretation of a very technical subject.

LOUIS MOYD, *Secretary*

Academy of National Sciences, Oct. 6, 1938

President Harry Trudell called the meeting to order on October 6th, 1938. The present officers were re-elected for the 1938–9 season: President, Harry W. Trudell; Vice President, Morrell G. Baldwin; Secretary, Louis Moyd; and Treasurer, Wiley H. Flack.

The subject for the evening was the reporting of summer trips. Mr. Morgan collected at many localities. He obtained magnetite and pyrite crystals from Chester, Vt., gummite, uranophane, uraninite, and autunite from Grafton, N. H., triphyllite and purpurite from Newry, Maine, and golden beryl from Easthampton, Conn.

Mr. Varni showed cat's eye tourmaline from Newry, Me.

Mr. Roedder found titanite at Lake Clear in Renfrew Co., Ont., very fine malachite at Bridgeport, Pa., pyrrhotite and an acicular pyroxene at Hillburn, N. Y.

At the Sparta Junction, N. J., quarry, Mr. Moyd collected stibnite associated with brown tourmaline, also plates of the vermiculite, philadelphite, at O'Neill's quarry, in Philadelphia.

Mr. Baldwin, reporting for Mr. D'Ascenzo, collected datolite, epidote, and babingtonite from Westfield, Mass.

Mr. Poppe described a trip through North and South Carolina, obtaining emeralds at the Crabtree Mt. mine, euxenite and thulite at Spruce Pine.

Mr. Toothaker described the use of a molding material known as "rubber latex" for making casts of specimens too delicate to move.

The first meeting of the new Philadelphia Geological Society, to be held on October 20th, 1938, was announced by its secretary, Mr. Adolph Meier.

LOUIS MOYD, *Secretary*

Correction

In the paper on "Prehnite from Coopersburg, Pennsylvania" (vol. **23**, p. 583), the form *p* given as {221} in the abstract and text, and as {211} in the table, should be changed to read {112}.

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Barksdale, J. D.	Thursday	4:40 P.M.
Behre, Charles H. Jr.	Thursday	2:17 P.M.
Bell, James F.	Thursday	9:10 A.M.
Berman, Harry	Wednesday	3:42 P.M.
Berry, L. G.	Wednesday	3:30 P.M.
Bloom, Mortimer C.	Thursday	11:03 A.M.
Bray, Joseph M.	Thursday	4:52 P.M.
Buerger, Martin J.	Thursday	10:03 A.M.
Bullard, Fred M.	Wednesday	4:02 P.M.
Coombs, H. A.	Thursday	3:57 P.M.
Donnay, J. D. H.	Thursday	10:20 A.M.
Fleischer, Michael	Thursday	10:43 A.M. 4:15 P.M.
Foshag, William F.	Wednesday	2:30 P.M.
Frondel, Clifford	Thursday	9:25 A.M.
Fuller, Richard E.	Thursday	3:57 P.M.
Gaines, R. V.	Wednesday	4:27 P.M.
Goldich, Samuel S.	Thursday	4:27 P.M.
Goodspeed, G. E.	Thursday	3:57 P.M.
Gruner, John W.	Thursday	3:05 P.M.
Hagner, Arthur F.	Thursday	9:42 A.M.
Henderson, Edward P.	Wednesday	3:50 P.M.
Ingerson, Earl	Thursday	2:52 P.M.
Jarrell, O. W.	Wednesday	4:35 P.M.
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Landes, Kenneth K.	Thursday	2:40 P.M.
Larsen, Esper S. 3rd	Wednesday	By title
McConnell, Duncan	Thursday	9:00 A.M.
Meen, V. Ben	Wednesday	4:47 P.M.
Meier, Adolph E.	Wednesday	5:10 P.M.
Merwin, H. E.	Thursday	10:55 A.M.
Morey, G. W.	Thursday	4:15 P.M.
Murdoch, Joseph	Thursday	By title
Page, Lincoln R.	Thursday	3:45 P.M.
Parrish, William	Thursday	3:20 P.M.
Peacock, Martin A.	Wednesday	3:17 P.M.
Pecora, William T.	Thursday	2:00 P.M.
Rogers, Austin F.	Wednesday	3:00 P.M.
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Slawson, Chester B.	Wednesday	2:42 P.M.
Stevenson, Louise S.	Thursday	3:37 P.M.
Switzer, George	Wednesday	4:15 P.M.
Thomson, Ellis (Grand Ballroom)	Thursday	11:30 A.M.
Tomlinson, W. Harold	Wednesday	4:57 P.M.
Tunell, George	Thursday	10:55 A.M.
Waldschmidt, W. A.	Wednesday	4:27 P.M.
Webb, Robert W.	Wednesday	By title
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Winchell, A. N.	Thursday	3:12 P.M.
Wolfe, C. W.	Thursday	11:19 A.M.

A HISTORY OF THE STUDY OF ORE MINERALS

(*Presidential Address*)

ELLIS THOMSON

A history of progress made in the study of ore minerals from the start of the last century up to the present day. The developments along the main avenues of approach are passed in review. These include studies of general methods, abrasives and polishing methods, chemical methods, mill-products, quantitative macroscopic and microscopic analysis, technique, and *x*-ray methods.

SILICIFIED WOOD IN DOLOMITE*

JULIAN D. BARKSDALE†

Small logs and broken pieces of jet black silicified wood occur in dolomite beds of Karnic age outcropping in the Sonoma Range, Nevada. In thin sections some of the specimens of wood, tentatively identified as *Araucarioxylon*, show perfect preservation of their cellular structure by the infiltration of siliceous solutions now crystallized as quartz. Single anhedrons of quartz sometimes include several cells filling even the smallest openings in the cell walls. The crystallization of the quartz in other specimens has disrupted the cell walls and produced a coarse pseudo-cellular structure controlled by the crystallographic directions in the growing quartz grains as they attempted to clear themselves of the carbonaceous material. The difference in type of preservation is thought to be due to the difference in condition of the woods at time of silicification. The black color of the wood is due entirely to its carbonaceous content. Chips fired in a ceramic furnace have the appearance of unglazed white tile.

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* Presented through the Geological Society of America.
† Introduced by G. E. Goodspeed.

EUROPEAN COLLOFORM ORES OF MISSISSIPPI VALLEY TYPE*

CHARLES H. BEHRE, JR.

Lead-since ores of "Mississippi Valley type" in certain districts of western Europe, like those of the Upper Mississippi Valley district in the United States, show distinctive mineralogic features. In calcareous country rock the ore and gangue minerals, as usual and as already noted in the literature, are typically blende (often light-colored), galena, pyrite (and marcasite), barite, fluorite, calcite, dolomite, ankerite, and quartz. Especially characteristic are the colloform masses of wurtzitic blende banded alternately with the other sulphides, galena being largely in the interior of the masses. In districts where the country rock is non-calcareous, these types are not known; the minerals of the gangue change and the colloidal appearance of the ore minerals is conspicuously absent, as especially well shown at Aachen and in the Rhine Valley.

These facts suggest that (1) the calcium ions in the gangue minerals and (2) the colloform structures of most of the ores are due to the influence of the calcareous country rock.

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* Presented through the Geological Society of America.

THE MORPHOLOGY OF MECHANICAL TWINNING IN CRYSTALS

JAMES FORBES BELL

Since the discovery of mechanical twinning in calcite by Brewster in 1816, mineralogists and crystallographers have used the morphologic relationship between the faces of a crystal before and after deformation to determine the twinning elements which can be mechanically produced in crystals. These relationships have been used in connection with the constants of a strain ellipsoid developed by a process of simple shear which was proposed as a geometrical means of describing mechanical twinning by Liebisch in 1889. Analytical expressions for the indices of a crystal face in the untwinned crystal in respect to the indices of the same face after reorientation and referred to the axes of the twinned crystal in terms of the constants of a strain ellipsoid were derived by O. Muegge in 1889. These formulae have been used as an indirect solution of the twinning elements by most crystallographers since that time. A new and direct graphic solution of the twinning elements from the relative positions in respect to the original crystal axes of two or more faces before and after deformation is presented.

The differences between the morphology of a mechanically twinned crystal and a growth twin involving the same twinning elements are explained.

A compilation of all of the work which has been done on mechanical twinning and new investigations attempting to correlate the twinning elements and the crystal structure are now being carried on.

A MICRO-BALANCE FOR SPECIFIC GRAVITY DETERMINATION

HARRY BERMAN

A micro-balance of the torsion type has been applied, after slight modification, to the measurement of specific gravities of fragments from 3 to 50 milligrams. The attainable accuracy is well within one per cent, and the time required for the necessary measurement is only a few minutes.

COMPOSITION AND OPTICS OF COPIAPITE

L. G. BERRY

From x-ray and density measurements on analysed copiapite from Chuquicamata, Chile, Peacock has obtained triclinic structural elements and the cell formula:

$$X(\mathrm{OH})_2\mathrm{Fe}'''_4(\mathrm{SO}_4)_6 \cdot n\mathrm{H}_2\mathrm{O}$$

in which X represents several bases amounting to one oxygen equivalent.

Reduction of many analyses of copiapite to 6 atoms of sulphur, instead of the usually accepted 5, confirms this formula and shows that the component X may be $\frac{2}{3}\mathrm{R}'''(\mathrm{Fe}''', \mathrm{Al})$, 1 $\mathrm{R}''(\mathrm{Fe}''$, Mn, Cu, Zn, Ca, Mg), or 2 R'(Na, K), and the full value of n is 20. For the varieties in which X is mainly Fe''', Fe'', or Mg (each represented by several good analyses), the names *ferricopiapite* (natural and artificial), *ferrocopiapite* and *magnesiocopiapite*, respectively, are proposed. For the variety in which X is mainly copper the name *cuprocopiapite* was recently proposed by Bandy. Ferricopiapite and cuprocopiapite are also optically distinguishable from ferrocopiapite or magnesiocopiapite, which are optically similar.

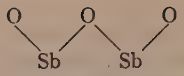
THE MECHANISM OF THE GENESIS OF POLYMORPHOUS FORMS

MORTIMER C. BLOOM

Polymorphous forms are found throughout the mineral kingdom under conditions of apparent thermodynamic instability. The mechanism of the genesis of such forms is the subject of this paper.

In the $\mathrm{Sb_2O_3}$ system, precipitation from pure aqueous solutions gives the stable senarmontite structure. Sufficiently acid solutions generate the unstable valentinite structure which contains some of the acidic constituents in solid solution, thus increasing its thermodynamic stability. Acid concentration is not the sole factor. The anion of the acid has a marked effect.

These results are determined by (a) the nature of the groups in solution, (b) the nature of the available crystal structures. The low temperature structure of $\mathrm{Sb_2O_3}$ consists of discrete $\mathrm{Sb_4O_6}$ molecules, the high temperature structure of chains composed of units of the following type:



Acid antimonious solutions contain antimony predominantly in the form of SbO^+ ions and organization into the valentinite chains is easily effected by elimination of H_2O between two SbO–OH groups. Recent crystal structure work has shown analogous groups in α-FeOOH, β-FeOOH, AlOOH, and MnOOH. That such groups are formed in acid antimonious solutions is indicated by the fact that precipitates from such solutions are very hydrous.

The valentinite structure has large channels capable of housing HCl readily, $HClO_4$ with some distortion. HCl gives rise to the valentinite structure at acid concentrations where $HClO_4$ gives rise to a mixture predominantly of the senarmontite structure.

Analogous studies will probably indicate analogous mechanisms for the genesis of polymorphs in other systems.

ILMENITE-HEMATITE-MAGNETITE RELATIONS IN SOME EMERY ORES

JOSEPH M. BRAY

The major mode of occurrence of hematite and ilmenite in emery ores from a number of localities is in the form of unique exsolution intergrowths, suggesting unusual crystallization-temperature-solution conditions. Magnetite, not a component of these exsolution intergrowths, is the most abundant opaque constituent in some polished sections, but is rare or totally absent in others. Ilmenite exsolves from hematite to sharp magnetite-hematite boundaries, showing that much of the hematite now present crystallized originally as hematitite, and is thus not a later replacement product of magnetite. Some replacement of magnetite by hematite is noted, but only a minor percentage of the total hematite present has formed in this manner.

Ilmenite of a single age often exsolves parallel to two crystallographic directions within hematite. In addition, two readily distinguishable ages of exsolution ilmenite in hematite are often observed. The ilmenite bodies of each age have a characteristic orientation in the hematite. The original solid solution varied from dominant hematite to dominant ilmenite.

Undoubted exsolution of hematite from corundum is very well shown in some sections. A further study of these intergrowths is in progress.

THE CRYSTAL STRUCTURE OF GUDMUNDITE

M. J. BUERGER

The crystal structure of gudmundite, FeSbS, has been completely determined. The ordinary gudmundite "crystal," in common with other members of the arsenopyrite group, is actually a twinned composite simulating a single orthorhombic individual. The composite gives orthorhombic *x*-ray diffraction effects, but a properly separated fragment gives monoclinic diffraction effects. The space group is C_{2h}^6. New, revised, cell data are:

	referred to primitive cell $P2_1/c$	referred to side-centered cell $B2_1/d$ (axes comparable with marcasite axes)
	a=6.02 A.	A=10.00 A.
	b=5.93	B= 5.93
	c=6.02	C= 6.73
	β=67°52′	β=90°00′
Formula weights per cell	4 FeSbS	8 FeSbS

calculated density..................6.93

All atoms are in the general position. A very intensive parameter study leads to the following positions of the atoms:

	$P2_1/c$			$B2_1/d$		
atom	x_a	y_b	z_c	X_A	Y_B	Z_C
Fe	−.300	.015	.300	0	.015	.300
Sb	.149	.131	.132	.140	.131	−.008
S	−.356	.145	.667	.156	.145	.511

The interatomic distances found in gudmundite confirm the author's earlier work regarding the abnormal interatomic distances in the members of the marcasite, löllingite, and arsenopyrite groups.

THE ROSEBUD METEORITE, MILAM COUNTY, TEXAS*

FRED M. BULLARD

The Burlington Meteorite, received by the University of Texas in 1915, is listed as the Rosebud Meteorite in several catalogues but has not been described up to the present time. The specimen, which weighs 54.9 kilograms, is an almost perfect conoid shaped mass with well developed radial pittings on the front surface. The apex is smooth. In composition the meteorite is of the stony type with slightly more than 13% metallic content. It contains well developed chrondules consisting, for the most part, of olivine and enstatite. A chemical analysis, spectrographic analysis, and a petrographic description are given.

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* Presented through the Geological Society of America.

CRYSTAL SPACE-GROUPS DETERMINED WITHOUT *X*-RAYS

J. D. H. DONNAY

The concepts of *multiple indices*[1] and of the two types of zonal distribution (*simple zones* and *double zones*)[2] are necessary prerequisites for the understanding of the present communication. Orthorhombic crystals only are considered here; similar results are obtained for other systems.

I. Zones of faces that are not perpendicular to possible glide-planes determine the *unit cell* and the *lattice centering.*

II. Zones of faces perpendicular to possible glide-planes indicate the presence or absence of a glide. The character of the axial zones, imposed by the lattice, is modified by *glide-planes:* (1) The dominant face of a simple zone may be shifted towards a pinakoid, as when (012) predominates over (011). The shift indicates the glide direction; e.g., a shift towards the *c* face indicates a *c* glide-plane. This occurs in primitive and one-face centered lattices. (2) A simple zone going into a double zone means an *n* glide-plane (in *P* lattice) or a *d* glide-plane (in *F* lattice). (3) A double zone going into a simple zone means a glide-plane to be lettered by either pinakoid of the zone (in *I* lattice).

In case there is no glide-plane, a pinakoid whose indices are not already doubled by the lattice, may have them doubled by a *screw-axis* (in primitive and one-face centered lattices).

Such simple rules enable one to read directly, from the gnomonic projection, the Mauguin symbol of the space-group (or possible space-groups). Examples: chalcomenite, epsomite, enargite, cerussite, danburite, andalusite, brookite, NH_2SO_3H, carnallite, hemimorphite, natrolite, sulfur.

---

[1] *Amer. Min.*, **22** (Palache volume), 446–467, 1937.

[2] Ann. Soc. géol. Belgique, **61**, B 260–287, 1938.

DEHYDRATION AND *X*-RAY STUDY OF POLLUCITE

MICHAEL FLEISCHER AND C. J. KSANDA

Previous *x*-ray studies of pollucite have led to a suggested crystal structure which is at variance with the chemical composition found by analysis, and with the behavior of the water present in the mineral. Dehydration curves have been obtained for pollucite specimens from Hebron, Maine, and from the island of Elba, and the material has been studied optically and röntgenographically before and after dehydration. The crystal structure, the chemical composition and the role of the water in the mineral are discussed in the light of the new evidence obtained.

PETROLOGY OF THE SHALLOWATER METEORITE

W. F. FOSHAG

The meteorite was found in 1936, near Shallowater, Lubbock County, Texas. It is an extraordinarily coarse diogenite, made up of enstatite 83½%, forsterite 5%, oligoclase ($Ab_{83}An_{17}$) 1½%, nickel-iron and troilite 10%. The silicates are iron free (enstatite 4% FeO). The association of iron free silicates with metallic iron is considered.

CRYSTAL HABIT VARIATION IN SODIUM FLUORIDE

CLIFFORD FRONDEL

An experimental study was made of the effect of foreign materials on the habit of growing crystals of NaF and other NaCl-type alkali halides. Approximately 250 inorganic and organic cosolutes, including 120 dyes, were investigated. The inorganic cosolutes which effect variation from the ordinary (100) habit of NaF fall into two groups:

(1) Cosolutes which afford OH^- ion directly or by hydrolysis, and certain organic cosolutes which contain OH groups cause an octahedral habit. The variation results from the substitutional adsorption (surface isomorphism) of OH^- for F^-, such as shown by Buckley for the adsorption of RO_4 ions by K_2SO_4, $KClO_3$, etc. The variation to octahedra finds explanation in Kossel's and Stranski's analysis of the growth of ionic NaCl-type crystals.

(2) Cosolutes which react chemically to form compounds with NaF cause variation in habit, as found by Retgers and Orloff for other alkali halides. Experimental evidence indicates that the adsorption is not by substitution, but involves the formation of a new, essentially two-dimensional, crystal phase held in ordered apposition to the surface NaF ions. The direction of variation is related to structural coincidences between NaF and crystals of the adsorbed compound. This mechanism illustrates the view of habit variation taken by Bunn.

Extremely few dyes are effective with the alkali halides, in contrast to K_2SO_4, etc., and their action is specific for different halides. The arrangement of polar hydroxyl or sulphonate groups in the dye influences the adsorption. Dye adsorption by neutral, (100), planes is common, contrary to France's theory of adsorption by charged planes.

PERTHITE FROM TORY HILL, ONTARIO

SAMUEL S. GOLDICH AND JAMES H. KINSER

An unusually well-developed perthitic intergrowth of microcline and albite was discovered in pegmatite masses occurring in syenite near Tory Hill, Haliburton County, Ontario. Film and vein perthite are both recognized. In the latter type, the albite is in braid-like veins trending parallel to the trace of the front pinacoid (100). These veins are composed of intertwining blebs of albite which are parallel to the prism faces, (110) and (1$\bar{1}$0), arranged in two superimposed *en echelon* groups forming the braid. Striking features of the intergrowth are the uniformity in orientation and in size of the blebs and the high percentage of albite. Gradations from this regular intergrowth into less regular patterns are believed to be significant in considering some of the theories which have been advanced for the origin of perthites. Petrographic data indicate that the potassic and sodic members of the intergrowth are relatively pure. The composition from a chemical analysis is Ca-f, 0.1; Na-f, 57.7; K-f, 42.2.

METASOMATISM OF A SHALE TO AN IGNEOUS APPEARING ROCK*

G. E. GOODSPEED, RICHARD E. FULLER, AND HOWARD A. COOMBS

During the summer of 1938, a cut in the western extension of the Mount Rainier highway from the southern entrance of the Park at Ohanapecosh disclosed a transition in the metasomatism of a shale. The rock belongs to a series of coal bearing sediments which are exposed along the road for over three miles, and which presumably represent the Puget Series of the Eocene. The shale is a dark reddish brown homogeneous rock with fine jointing, and occurs here both in normal beds, and as rounded, angular or irregular blocks ranging from a fraction of an inch to ten feet or more in diameter, enclosed in a light gray rock containing megascopic plagioclase and quartz. Although the contact is locally sharp, it more commonly shows in less than an inch, a gradation from the unaltered shale to a rock which by itself would be called a porphyritic dacite and be classed with the Keechelus volcanic series. This transitional facies is marked by the development of feldspathic porphyroblasts in the shale, and by the change of the rock to a pale greenish shade owing to disseminated chlorite. The igneous appearing rock at the contact shows no sign of chilling, while the groundmass locally appears to be indistinguishable from the shale. Some blocks of the shale exhibit fine veinlike extensions of the igneous appearing rock with a coarseness of grain which denotes a crystalloblastic origin. The size and shape of the blocks of the fragile shale preclude a pyroclastic origin and give additional evidence of a metasomatic replacement, in which relics of the shale survive in various stages of transformation.

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* Presented through the Geological Society of America.

THE BEHAVIOR OF SERPENTINES BETWEEN 500° AND 650°C.

JOHN W. GRUNER

In connection with the study of the structure of serpentines, it was shown by Selfridge and the writer that there are two distinct structures which were named antigorites and chrysotiles by them. Contemporaneously Caillère[1] in an extensive study had shown that two types of serpentine (called α and β antigorites by her) exist. Caillère's distinction is based on the different behavior when heated and the appearance of their thermal curves. The writer finds that there is no agreement between the two classifications. A chrysotile may be either an α or β antigorite, or one of the α or β antigorites of Miss Caillère may be an antigorite or chrysotile of the writer.

It was found that all chrysotiles change to olivine (and probably colloidal silica) if held in air at a temperature of 560°C. for 4 to 19 days. The antigorites on the other hand, are not changed so rapidly and some of them seemed to remain serpentine after 34 days as seen by x-rays. In an atmosphere of CO_2 all of them change to olivine at 560°C. within 2 to 22 days. At 650°C. in air even the antigorites change to olivine relatively rapidly. No indication of the formation of enstatite was found at either temperature which is not in agreement with results reported by Caillère.

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[1] Caillère, S., Bull. Soc. Franc. Min., vol. 59, p. 163, 1936.

ADSORPTIVE CLAYS OF THE TEXAS GULF COAST

ARTHUR F. HAGNER

Numerous clay pits containing an abundance of material suitable for the clarification and purification of petroleum products are found along the Texas Gulf Coastal Plain. Microscopic, chemical, and *x*-ray examinations indicate that the principal mineral constituent is montmorillonite. Microscopic textures and structures, when well preserved, are significant of origin. Many beds represent the result of alteration in situ of volcanic ash. Substantial amounts of kaolinite, halloysite, and allophane occur in some deposits, indicating variations in origin. The amount of alteration is variable. Some of the original material has altered sufficiently to clay to form fuller's earth of usable quality. In certain deposits alteration has been so complete as to obliterate any definite evidence of origin of the clay.

The waxy character of many moist clay layers has proved of interest. Waxy clays contain more nearly pure montmorillonite than the other types which are soft, granular and kaolinitic. The waxiness may be attributed to the unusual hydration characteristics of montmorillonite. Kaolinitic mixtures occur in the northeastern part of the clay belt, whereas the more nearly pure montmorillonite occurs in the southwestern part. The prevalence of kaolinitic material in the fuller's earths of eastern Texas may account for efficiency ratings below those of the Georgia-Florida fuller's earths.

A review of the literature, correlated with field observations, indicates that the clays of eastern Texas have formed during the Eocene, and Oligocene or Miocene epochs. Correlation of physical, chemical, and optical properties with adsorptive efficiency has been attempted.

CHEMICAL STUDIES OF HEXAHEDRITE METEORITES FROM CHILE

E. P. HENDERSON

A great many of the siderites from Chile belong to the hexahedrite class of meteorites. This suggests that either there has been a shower of this type of material or if these are unrelated falls, then perhaps a chemical study would detect some differences between them. Five new analyses of recently acquired Chilean meteorites (Puripica, Sierra Gorda, Rio Loa, Negrillos, and Coya Norte) are given and compared with each other, as well as with other analyses of this type of meteorite. Between all these Chilean hexahedrites a remarkable agreement was found and if this group alone is considered, it would suggest that all five falls are from the same. However, when these analyses are compared with others of this same classification of meteorites and from widely scattered areas over the world, there still is found the same close agreement, which suggests that this is the fundamental type of material in iron meteorites. Comparing these analyses with those of kamacite, a component in octahedrites, there is also a striking agreement. Henceforth it certainly seems more logical to consider hexahedrites as meteorites composed entirely of kamacite. Metallographic studies between kamacite and hexahedrites support this conclusion and more detailed studies are being made.

COMPARISON OF THE FABRICS OF XENOLITHS AND THE ADJACENT INTRUSIVE ROCK

EARL INGERSON

Fabric studies of two intrusions and their included xenoliths have been made: (1) The Port Deposit granodiorite in Maryland and (2) the Uncle Sam quartz monzonite porphyry near Tombstone, Arizona. The Port Deposit granodiorite has undergone metamorphism after its intrusion was completed, but the Uncle Sam porphyry is unmetamorphosed. Mica and quartz fabrics of the Port Deposit granodiorite and the xenoliths studied are identical. There is little mica in the Uncle Sam porphyry and none in its xenoliths, which are mostly quartzite. The quartz fabric of the inclusions is unlike that of the porphyry, indicating that the fabric of the inclusions was not produced during intrusion. Presumably, then, the identity of fabric in the Port Deposit granodiorite was produced by metamorphism of the intrusive and its xenoliths after intrusion rather than by working over of the inclusions during intrusion.

MARSHITE FROM CHUQUICAMATA, CHILE

O. W. JARRELL

A few specimens of marshite were recently found in the oxide ore body of the disseminated copper deposit at Chuquicamata, Chile. Its properties agree essentially with the previously described material from Broken Hill, N.S.W. A description of the new occurrence, complete index of refraction determinations, and a new analysis are presented.

AN EXPLANATION OF DIAMOND CUTTING IN TERMS OF ATOMIC STRUCTURE

EDWARD H. KRAUS AND CHESTER B. SLAWSON

Long experience of diamond cutters shows that the hardness of the diamond varies materially with the crystal surface on which the cutting or polishing is done. The hardness is least on planes parallel to faces of the cube. It is greatest on planes parallel to faces of the octahedron, and such planes can be worked only with great difficulty, if at all. The characteristics of diamond dust which make it suitable for sawing and polishing of the diamond are described. The directions in which these processes may be effectively done are indicated in terms of atomic structure. An explanation of the perfect octahedral cleavage is also given.

MINERALS OF EIGHT MILE PARK, COLORADO

KENNETH K. LANDES

Eight Mile Park is the partially wooded upland lying immediately north of Royal Gorge in Fremont County, Colorado. It is floored with crystalline rock of pre-Cambrian age. Granite pegmatites are abundant, and at least three of these have been exploited for feldspar. One deposit, the Mica Hill, has produced more feldspar than any other mine in the state.

The dominant minerals in the Park pegamatites are microcline and quartz. Muscovite is abundant, in some instances occurring in large radiating masses. Beryl crystals with a maximum diameter of two feet are common in the lower part of the Mica Hill open cut. Albite is subordinate. Garnet crystals occur near the margins of some of the pegmatites. An unexploited pegmatite east of Mica Hill contains abundant pink tourmaline and lepidolite. Black tourmaline is found with milky quartz in a hill to the southwest.

In most of these pegmatites the hydrothermal phase was relatively subordinate.

OVERITE, A NEW MINERAL FROM FAIRFIELD, UTAH

ESPER S. LARSEN, 3RD

Overite, $Ca_3Al_6(PO_4)_8 \cdot 20H_2O$, according to a preliminary analysis, is a new mineral from the variscite nodules of Fairfield, Utah. It is orthorhombic and occurs as pale green to colorless prismatic crystals, flattened on (010), in cavities in altered variscite. Cleavage: (010) perfect, (100) poor. $H=4$; $G=2.53$. Biaxial negative, $2V=75^\circ \pm 10^\circ$; $r>v$ weak; $X=c$, $Z=b$. $\alpha=1.568$, $\beta=1.574$, $\gamma=1.580$, all $\pm .002$. Elements (morphological): $a:b:c=0.7839:1:0.3794$. Structural lattice: $a_0=14.62$ Å, $b_0=18.68$ Å, $c_0=7.08$ Å; $a_0:b_0:c_0=0.7827:1:0.3788$; $V_0=1936$ cubic Å. Cell contains $2[Ca_3Al_6(PO_4)_8 \cdot 20H_2O]$.

The mineral is named after Mr. Edwin Over of Colorado Springs, Colorado, who, with Mr. Arthur Montgomery, recognized the mineral as new and collected sufficient for a chemical analysis.

THE SYMMETRY OF PHOSPHOSIDERITE

DUNCAN MC CONNELL

An investigation involving the use of Laue, powder and oscillation methods, as well as etching experiments, demonstrates that phosphosiderite is monoclinic with: $a_0=5.30$, $b_0=9.79$, $c_0=8.67$ Å (all ± 0.02 Å) and $a:b:c=0.541:1:0.886$, $\beta=89$–$90°$. This mineral displays pronounced pseudosymmetry which impedes certain measurements. The space group is probably $C_{2h}^2=2\ Ci\text{-}2$. If the unit cell is assumed to contain four molecules of $FePO_4 \cdot 2H_2O$ the theoretical density becomes 2.74, as compared with a recorded value 2.76.

Phosphosiderite is isomorphous with metavariscite only if the latter is pseudosymmetric and, in reality, monoclinic also. Strengite is probably dimorphous with phosphosiderite.

VESUVIANITE FROM GREAT SLAVE LAKE REGION, CANADA

V. BEN MEEN

The crystallographic, optical and chemical properties of well-formed crystals of vesuvianite from this new locality are discussed.

AN ASSOCIATION OF HARMOTOME, CORUNDUM AND HYALOPHANE AT GLEN RIDDLE, PA.

ADOLPH E. MEIER AND W. HAROLD TOMLINSON

In a recent paper an occurrence of harmotome in a basic dike at Glen Riddle, Delaware Co., Pa. was described.* Corundum and potash-barium feldspar were so associated in the rock matrix that a paragenetic relation between all three minerals was indicated. Further study indicates that they were formed at various stages of the same dynamic hydrothermal sequence.

There are two types of hyalophane present, with an orthoclase-celsian content of $Or_{85}Cn_{15}$ and $Or_{90}Cn_{10}$. Both types occur as antiperthites with andesine or oligoclase, or as separate grains in close association with the latter. An occasional perthite occurs in the more alkaline association. Four types of plagioclase are present. The range in anorthite content is from An_{60} to An_{15}. Intermediate types are An_{20} and An_{40}. Spatial relationships of the feldspars are such as to impart to the dike an anorthositic core and a gabbroic rim. Intermediate feldspars, hyalophane and corundum occur mainly along variously spaced crush zones parallel to the foliation in the dike.

The contemporaneous deposition of the hyalophane and corundum and the later deposition of harmotome is considered to be the result of

(1) deformation of a thin dike of anorthositic gabbro, emplaced in pyroxenite, by forces accompanying the intrusion of a hornblende granite close by,

(2) infiltration during or after stress along favorable channels of hydrothermal potash barium solutions emanating from the granite and setting up a series of reactions which resulted in the deposition of mineral suite described.

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* Given at the Eighteenth Annual Meeting of the Min. Soc. of Amer.

LIQUID-VAPOR EQUILIBRIA IN THE SYSTEM K_2O-SiO_2-CO_2-H_2O*

G. W. MOREY AND MICHAEL FLEISCHER

Although there is general agreement that hydrothermal and pneumatolytic processes play important roles in the formation of ore deposits, there is so little physico-chemical data available on the properties of complex solutions at high pressures and temperatures that it is not possible at present to pass upon the validity or competency of the various mechanisms which have been suggested to account for the mode and order of ore deposition. As the first step towards obtaining such data, we have designed an apparatus with which to study the equilibrium distribution of two volatiles between the liquid and vapor phases at high temperatures and pressures. The present paper reports the results obtained in the system K_2O-SiO_2-CO_2-H_2O at 500°C. The effect of changing potash-silica ratios on the distribution of the volatiles is discussed. The change in composition of the vapor phase with diminishing pressure at constant temperature is shown graphically for various initial compositions.

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THE CRYSTALLOGRAPHY OF VEATCHITE

JOSEPH MURDOCH

Some terminated crystals of veatchite, the newly discovered calcium borate from Lang, California, have been measured on the goniometer, and the elements calculated. Using the published values for the unit cell dimensions, the elements are as follows:

$a:b:c=0.163:1:0.998 \qquad \beta=121°2'$
$p_0:q_0:r_0=6.1227:0.8551:1 \qquad \mu=\ 58°58'$
$r_2:p_2:q_2=1.1693:7.1600:1$
$p_0'=7.1455 \qquad q_0'=0.998 \qquad x_0'=7.7472$

The following forms are tentatively recorded: (010) (100) (001) (017) (014) (013) (025) (023) (056) (011) (054) (043) (021) (230) (120) (140) (150) (160) ($\bar{1}$66) ($\bar{1}$.7.12). Of these forms, (010) is always present, well developed, but the clinodome and prism zones are characterized by many narrow and often indeterminate faces, of which the more definite have been selected. Pyramids are rare, only three faces having been found on eight crystals.

INTRODUCTION OF FELDSPAR INTO INCLUSIONS, ELLSWORTH, NEW HAMPSHIRE

LINCOLN R. PAGE

Inclusions of quartz-biotite schist in a porphyritic facies of the Kinsman quartz monzonite, one-half mile east of the north end of Stinson Lake, town of Ellsworth, New Hampshire, show porphyroblasts of soda-feldspar which appear to have been introduced from magmatic sources. These porphyroblasts, up to 6 cm. in length, are similar in appearance to the phenocrysts in the quartz monzonite, but the latter, dominantly microcline feldspar with small amounts of myrmekite, contain few inclusions of the groundmass. The porphyroblasts are present as separate carlsbad twinned crystals and as groups of grains of different optical orientation. Abundant inclusions of the groundmass minerals are present in both occurrences. In some cases these inclusions are scattered throughout individual crystals and in others they are grouped together and surrounded by rims of feldspar up to 5 mm. thick. Replacement textures, inclusions of original minerals within feldspar rims, and mineralogic and field relations strongly suggest that the soda has been added to the quartz-biotite schist from igneous sources.

THE MEASUREMENT OF REFLECTIVITY AND COLOR OF MINERALS

WILLIAM PARRISH

Recently, an attempt has been made to identify opaque minerals by determining their reflectivity by means of auxiliary microscope apparatus such as the Berek slit microphotometer or Orcel photoelectric ocular. In general, measurements obtained with these instruments do not lead to a unique determination of the mineral.

This paper describes a technique for the measurement of the diffuse reflectivity and other data by use of the Hardy recording photoelectric spectrophotometer, which is also known as the color analyzer (J.O.S.A., 28, p. 360, 1938). It has the advantages of accuracy to three significant figures, speed, completeness of data, and simplicity of operation; it is applicable to opaque and non-opaque minerals. The chief disadvantage of the instrument is its high cost. It operates automatically and plots a continuous spectrophotometric curve (reflectivity as a function of wavelength) for the entire visible spectrum in about one minute. The specimens may be natural crystal faces or prepared as metallic mirrors, polished surfaces, or powders. The reflectivity curves of about 100 minerals were determined on this instrument and each of these curves is unique.

The Handbook of Colorimetry (M.I.T., 1936) uses three terms to describe color on an absolute color scale: brightness, dominant wavelength, and purity. From the reflectivity curve one can easily calculate these terms and thus describe the precise color of the mineral.

Further experiments are in progress on the determination of the specular reflectivity, with the intention of using this constant to calculate refractive index, absorption, density, and conductivity.

CRYSTALLOGRAPHY OF COPIAPITE

M. A. PEACOCK

On copiapite from Chuquicamata, Chile, Palache obtained the hitherto unpublished triclinic elements:

$$a:b:c=0.4058:1:0.4039;\ \alpha=93°50',\ \beta=102°10',\ \gamma=99°21\tfrac{1}{2}'$$

X-ray photographs, kindly made by Buerger, on a crystal from the same locality, gave the following structural elements in the normal setting:

$$a_0=7.33,\ b_0=18.15,\ c_0=7.27\ \text{Å};\ \alpha=93°51',\ \beta=101°30',\ \gamma=99°23\tfrac{1}{2}'$$
$$a_0:b_0:c_0=0.404:1:0.401$$

On copiapite from Sierra Gorda, Chile, Ungemach (1935) noted 144 forms and obtained elements which, transformed to the normal setting, give:

$$a:b:c=0.4005:1:0.3971;\ \alpha=93°58\tfrac{1}{2}',\ \beta=102°08',\ \gamma=98°50'$$

These variations in the crystallographic elements of copiapite may be explained by the variations in the composition and optics discussed by Berry at this meeting.

In addition to affording a fine example of form development according to the Law of Bravais, a projection of the forms of copiapite presents a striking case of the problem of multiple morphological periods.

NEPHELINE-SYENITE PEGMATITES IN THE BEARPAW MOUNTAINS OF MONTANA

WILLIAM T. PECORA

In the western Bearpaw Mountains of Montana is situated a composite stock of Tertiary age, made up chiefly of pyroxenite, shonkinite, syenite and nepheline syenite. The pegmatites to be described are intimately associated with the nepheline syenite bodies as late segregations or with the adjacent older rocks as dike injections. The deposits are numerous, varying in width up to six feet and in length of outcrop up to a few hundred feet.

The primary minerals present are feldspar, nepheline, biotite, and garnet (melanite). Replacement minerals include sphene, ilmenite, fibrous and prismatic aegirine, eudyalite, lamprophyllite, and occasional metallic sulfides. Tabulations and discussions of chemical analyses and optical properties are also included. The mineral associations of these hitherto undescribed pegmatites are similar to those of other better-known localities such as the Kola Peninsula.

A MINERALOGICAL TRIP TO EUROPE

AUSTIN F. ROGERS

An account of collecting trips to Mill Close, Castleton, Llandudno, Saltbura, Fallowfield, Cornwall, Moresnet, Ytterby, Langban, Oslo, Snarum, Kongsberg, Langesund, Kragerö, Erje, Iveland, and Saalfeld.

An account of visits to establishments at Antwerp and Idae-Oberstein and to the museums and mineralogical institutes of London, Oxford, Cambridge, Edinburgh, Camborne, Brussels, Ghent, Louvain, Liege, Amsterdam, Leiden, Groningen, Copenhagen, Oslo, Stockholm, Upsala, Berlin, Zurich and Paris.

MONTICELLITE ROCK FROM CRESTMORE, CALIFORNIA

AUSTIN F. ROGERS

For many years the rare mineral monticellite (a double salt with the formula: $CaMgSiO_4$) was known from only one locality in this country (Magnet Cove, Arkansas).

In 1917 Eakle described it from the contact-metamorphic zone of Crestmore, where he found it with xanthophyllite in blue calcite. More recently Moehlman and Gonyer describe it as a minor constituent of a metamorphic silicate complex from Crestmore.

Crestmore probably ranks as the most prominent locality for monticellite, for the writer about a decade ago found it here in huge blocks in the "Wet Weather" quarry.

The monticellite rock is a pale brown medium-grained granulose massive rock with green spots of idocrase. The idocrase apparently replaces the monticellite and it seems likely that at least some of the massive idocrase at this locality is a replacement of the monticellite rock.

PRELIMINARY REPORT ON THE SYSTEM, $FeO-Al_2O_3-SiO_2$

J. F. SCHAIRER

In order to obtain more information on the compositions and stability relations of the FeO-bearing pyroxenes it will be necessary to obtain silicate equilibrium data for quaternary systems involving $CaO-FeO-Al_2O_3-SiO_2$ and $MgO-FeO-Al_2O_3-SiO_2$. Before beginning determinations on these quaternary systems it is necessary to know the relations in the system, $FeO-Al_2O_3-SiO_2$.

The system, $FeO-Al_2O_3-SiO_2$, is under investigation and substantial progress has been made in determining the liquidus surfaces of the several solid phases. Tridymite, cristobalite, spinel (hercynite), fayalite, mullite, and corundum liquidus surfaces have been determined in whole or in part. One eutectic and two reaction points have been located. So far no ternary compounds have been encountered at the liquidus temperatures.

RHYODACITE FROM THE TRANQUILLE PLATEAU, BRITISH COLUMBIA

LOUISE STEVENS STEVENSON

Siliceous lavas are very uncommon in the Tertiary volcanics of the British Columbia interior plateaus, and the present paper records what is believed to be the first such occurrence to be studied in petrographic detail. A plug-like outcrop of white, fine-grained, porphyritic rock was found in the upper Tranquille valley in a group of middle-Tertiary lavas. It has been identified microscopically as a rhyodacite, corresponding to 237E of Johannsen's classification. Phenocrysts of oligoclase, quartz, sanidine, and biotite are embedded in a microcrystalline groundmass. Results of optical study of the minerals, and of Rosiwal determinations, are given.

TWINNED OCTAHEDRA OF FLUORITE AND ASSOCIATED MINERALS FROM MT. ANTERO

GEORGE SWITZER

During the summer of 1938 a study was made of the pegmatites of the Mt. Antero region, in company with Mr. Arthur Montgomery and Mr. Edwin Over.

Fluorite crystals were found twinned by the usual law but showing only, or dominantly, the octahedron form, a new habit for this mineral.

The fluorite-bearing pegmatites may be grouped in five different types. The paragenesis of each type will be described and the habit-association relationships of some of the minerals pointed out. The minerals occurring in the pegmatites are feldspar, quartz, muscovite, beryl, phenakite, topaz, bertrandite, fluorite, limonite, and sulphur.

THE CORUNDUM IN THE GLEN RIDDLE DIKE

W. HAROLD TOMLINSON

Discussion of Corundum pegmatites and their connection with gabbro differentiates. Connection shown between corundum pegamatites and granite volatiles. Description given of corundum dike and associated rocks at Glen Riddle. Two reactions illustrated by which corundum is formed from excess alumina liberated from anorthite when attacked by volatile elements. A theory contending that all alumina available for corundum is carried in magma as anorthite and that corundum is formed by reaction between anorthite and volatile elements. This reaction at near magma temperatures. Application of this theory to some corundum localities.

POTASSIUM TETRATHIONATE AS AN EXAMPLE OF MONOCLINIC HEMIHEDRAL SYMMETRY

G. TUNELL, H. E. MERWIN, AND C. J. KSANDA

Crystals of potassium tetrathionate and potassium pentathionate were synthesized and analyzed by Dr. E. T. Allen in connection with an investigation of hot spring deposits in Yellowstone National Park, where pentathionate was found to occur in natural solutions. The crystallographic properties of the tetrathionate were determined in the present study also its space-group. Potassium tetrathionate is notable for its pronounced monoclinic hemihedrism, and was found by Messrs. Hendricks and Jefferson to have an unusually strong pyroelectric effect.

AN OCCURRENCE OF CHRYSOBERYL NEAR GOLDEN, COLORADO

W. A. WALDSCHMIDT AND R. V. GAINES

Chrysoberyl, found near Drew Hill, about ten miles from Golden, Colorado, occurs in a small granite pegmatite dike. The crystals and crystalline masses of chrysoberyl from this locality are exceptionally large. One tabular mass weighs slightly over two pounds. The largest single crystal found measures 11/16 inch in thickness, 1-9/16 inches in width, and 3.3/4 inches in length. All of the specimens of chrysoberyl thus far found in place are near the center of the dike in close association with massive quartz or quartz-muscovite segregations.

LARGE SPHENE CRYSTALS FROM SAN JACINTO MOUNTAINS, CALIFORNIA

ROBERT W. WEBB

Large sphene crystals disseminated in plutonic rocks are not commonly found. Recently an area in the batholith of the San Jacinto Mountains, Riverside County, California, has been found in which a microcline quartz-diorite contains crystals of sphene which are abundant in sizes up to $1'' \times \frac{1}{2}'' \times \frac{1}{2}''$. The crystals are perfectly formed euhedrons, occurring separately and in groups. Thousands of crystals of good size are obtaininable without difficulty from the decomposed rock. Microscopic examination shows the crystals to include subhedral grains of andesine and anhedrons of quartz. These relations and other features of the sphene indicate a late or secondary introduction of the sphene crystals.

MINERAL COMPOSITION OF HAWAIIAN CERAMIC CLAY

CHESTER K. WENTWORTH, ROGER C. WELLS, AND VICTOR T. ALLEN

Since 1935 small amounts of medium or light gray residual clay of ceramic quality have been found in restricted upland areas on Oahu, Maui, Molokai, and Kauai. The deposits take the form of thin underclays, always overlain by a well marked humus or peat layer at the modern surface, and usually underlain by thin but more or less continuous masses of iron pan followed by weathered, buff or brown residuum.

In every instance the clay occurs in sloping areas of little relief, remnants of original constructional surfaces of volcanic domes, which receive rainfall of 150 to 400 inches annually but have long remained free from significant disturbance by erosion or deposition. In elevations ranging from 2500 to 5500 feet, patches of more or less distinctive bog vegetation have developed and are apparently the basis of the reducing conditions under which a clay fairly low in iron has been produced.

Three complete chemical analyses show a rather variable composition, silica 34 to 57 per cent, alumina 22 to 26 per cent, iron oxides 3 to 9 per cent. Most surprising is over 14 per cent of titanium oxide in two of the samples. Preliminary petrographic studies indicate the derivation of the clay from basaltic lavas, the feldspar phenocrysts changing to kaolinite and the matrix originally feldspars and ferromagnesian minerals to illite. Elutriation concentrates from the clay contain plagioclase, ilmenite, and leucoxene. The latter minerals probably account for the high titanium which was derived from original ilmenite and titaniferous augite.

OPTIC PROPERTIES OF ORGANIC AND INORGANIC COMPOUNDS COMPARED

A. N. WINCHELL

A diagram has been prepared showing the optic properties of about 1000 organic compounds (including all those that have been measured). Such a diagram can be used for the rapid identification of any unknown compound which has been placed on it. By comparison with a similar diagram of optic properties of inorganic compounds it appears that organic compounds show considerably greater variation than the inorganic both in refringence and in birefringence.

SYMMETRY AND UNIT CELL OF HOPEITE

C. W. WOLFE

X-ray examination of hopeite gave the following cell lengths: $a_0 = 10.64$ Å, $b_0 = 18.32$ Å, $c_0 = 5.03$ Å; $a_0 : b_0 : c_0 = 0.5808 : 1 : 0.2745$; $M_0 = 1833.0 = 4[Zn_3(PO_4)_2 \cdot 4H_2O]$. In Spencer's work on this mineral where it was considered to be holohedral, the above axial relations may be expressed as b:3a:c. Ungemach later recognized the proper lengths, but thinking that hopeite represented a 33rd crystal class, that is, orthorhombic with but one plane of symmetry, he changed the setting to make this plane basal. The transformations from the Spencer setting and from Ungemach's setting to the structural one are respectively: 010/300/001 and 010/001/100.

A study of the spectral omissions plus consideration of symmetry limitations noted by Spencer, Ungemach, and the author (on new crystals) definitely fixes the symmetry of hopeite to be bisphenoidal with the space group $D_2^4 - P\,2_12_12_1$. The one, two, or three planes of symmetry commonly observed on hopeite are due to twinning, two of these twin laws having been demonstrated by earlier workers and the third, postulated by the author.